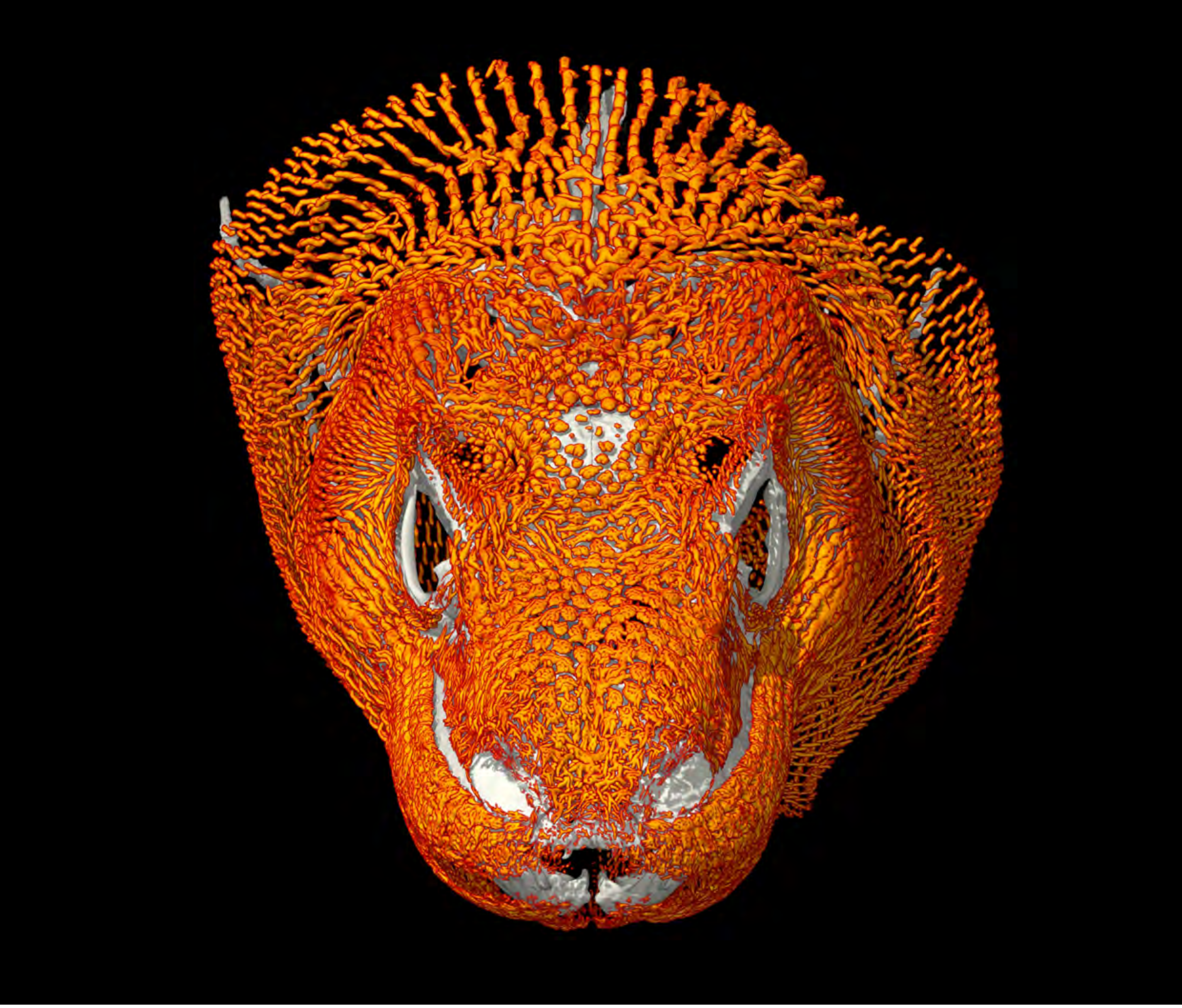

ToScA North America

6 – 8 June 2017, The University of Texas, Austin, TX

Program

ToScA
Tomography for Scientific Advancement

Event Management by

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Thank you to the University of Texas High-Resolution X-ray CT Facility (UTCT) for supplying the images used throughout this booklet.

Welcome

Chair: Dr Farah Ahmed (Natural History Museum, UK)

A warm welcome to the first annual ToScA North America! It is my pleasure to announce that Tosca North America is being launched at the University of Texas, and hosted by the Jackson School of Geosciences. ToScA was founded in 2013 at the Natural History Museum in London. It has grown from a local UK-based meeting to an international platform for scientists and Industry from all over the world. It has had attendance of over 450 delegates from over 15 countries in the last 4 years and is running in parallel in the UK, hosted by the University of Portsmouth in September 2017. By sharing ideas, networking across Industry and demonstrating innovative developments, the symposium provides an ideal arena for the international tomography community and associated Industry. ToScA North America will address key areas of science, including Multi-modal Imaging, Geosciences, Forensics, Increasing Contrast, Educational Outreach, Data, Materials Science and Medical and Biological Science.

We are grateful to the University of Texas for their support and I look forward to the plethora of talks and posters. The evening dinner takes form in a banquet cruise with the unique experience of seeing 1.5 million bats emerge from the Congress Avenue Bridge, providing a perfect environment for networking. ToScA promises a full and diverse scientific programme, and on behalf of the organising committee I hope you will find the symposium interesting and stimulating.

We look forward to welcoming you all.

Co-chair: Dr Jessie Maisano (The University of Texas, Austin, TX)

On behalf of the University of Texas High-Resolution X-ray CT Facility (UTCT) and the Jackson School of Geosciences, welcome to Austin! We are very excited to host the first ToScA Symposium outside of the UK.

This spring marks UTCT's 20th anniversary, and what better way to celebrate than by bringing together professionals, students, and industry representatives from across the country – and the pond – to talk about all things tomographic. In addition to two days of stimulating talks, including our renowned keynote speakers, we will embark on a dinner cruise on Lady Bird Lake during which we will watch the largest urban colony of Mexican free-tailed bats in the world emerge from under the Congress Avenue bridge – you can only do that in Austin!

Please enjoy your time in our great city, and do not hesitate to let your UTCT and Jackson School hosts know if we can be of further assistance.

Organising Committee & Invited Speaker List

Symposium Chairs

Dr Jessie Maisano, The University of Texas

Dr Farah Ahmed (ToScA Chair), Natural History Museum

Forensics

John Kappelman, The University of Texas

Multi-Modal Imaging

Stephen Gatesy, Brown University

Increasing Contrast

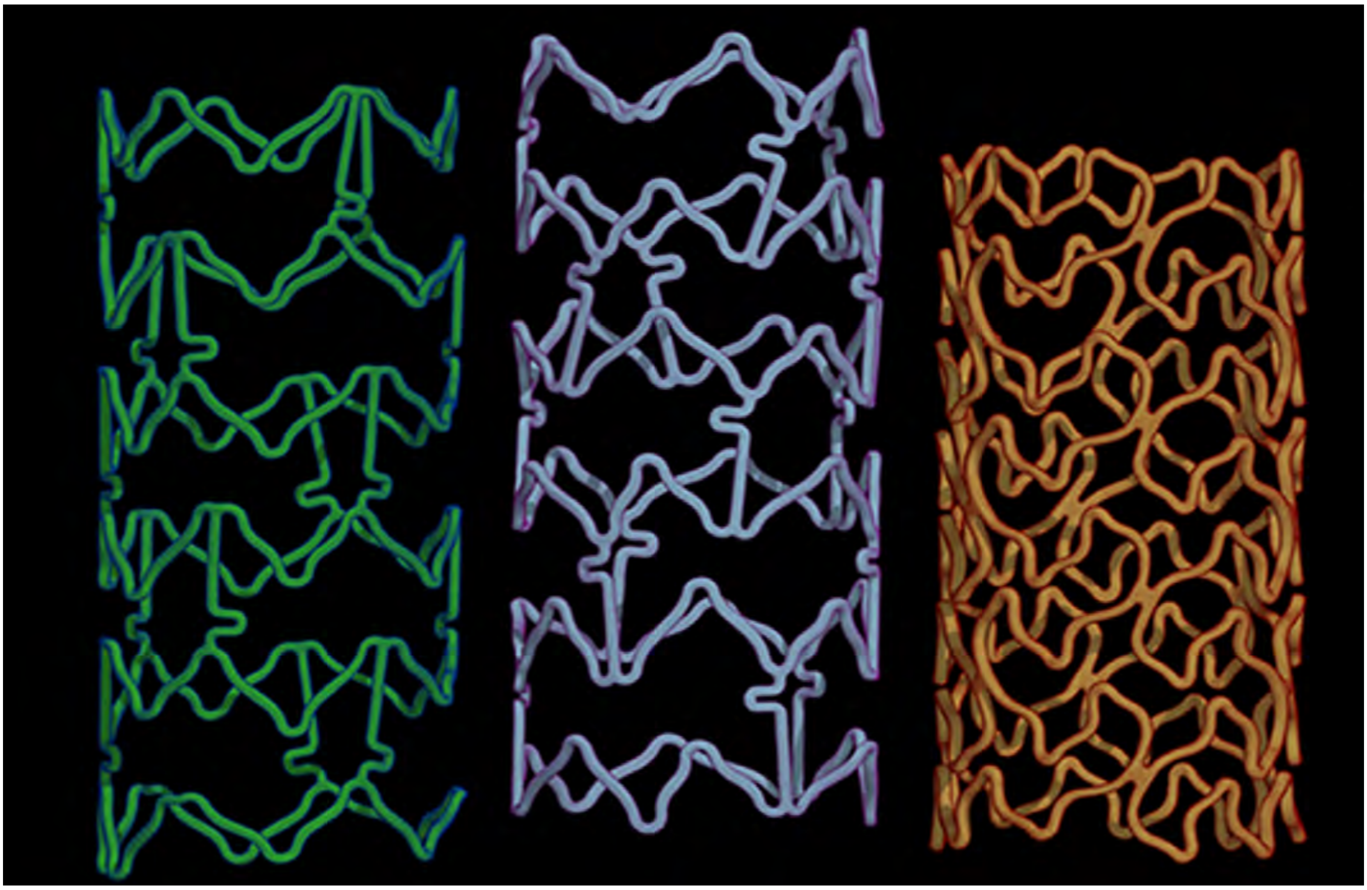
Lawrence Witmer, Ohio University

Geological Science

Richard Ketcham, The University of Texas

Data

Timothy Rowe, The University of Texas



The University of Texas, Austin, TX

History

In 1839, the Congress of the Republic of Texas ordered that a site be set aside to meet the state's higher education needs. After a series of delays over the next several decades, the state legislature reinvigorated the project in 1876, calling for the establishment of a "university of the first class." Austin was selected as the site for this new university in 1881, and construction began on the original Main Building in November 1882. Less than one year later, on September 15, 1883, The University of Texas, Austin, TX opened with one building, eight professors, one proctor, and 221 students — and a mission to change the world. Today, UT Austin is a world-renowned higher education, research, and public service institution serving more than 51,000 students annually through 18 top-ranked colleges and schools.

Jackson School of Geosciences

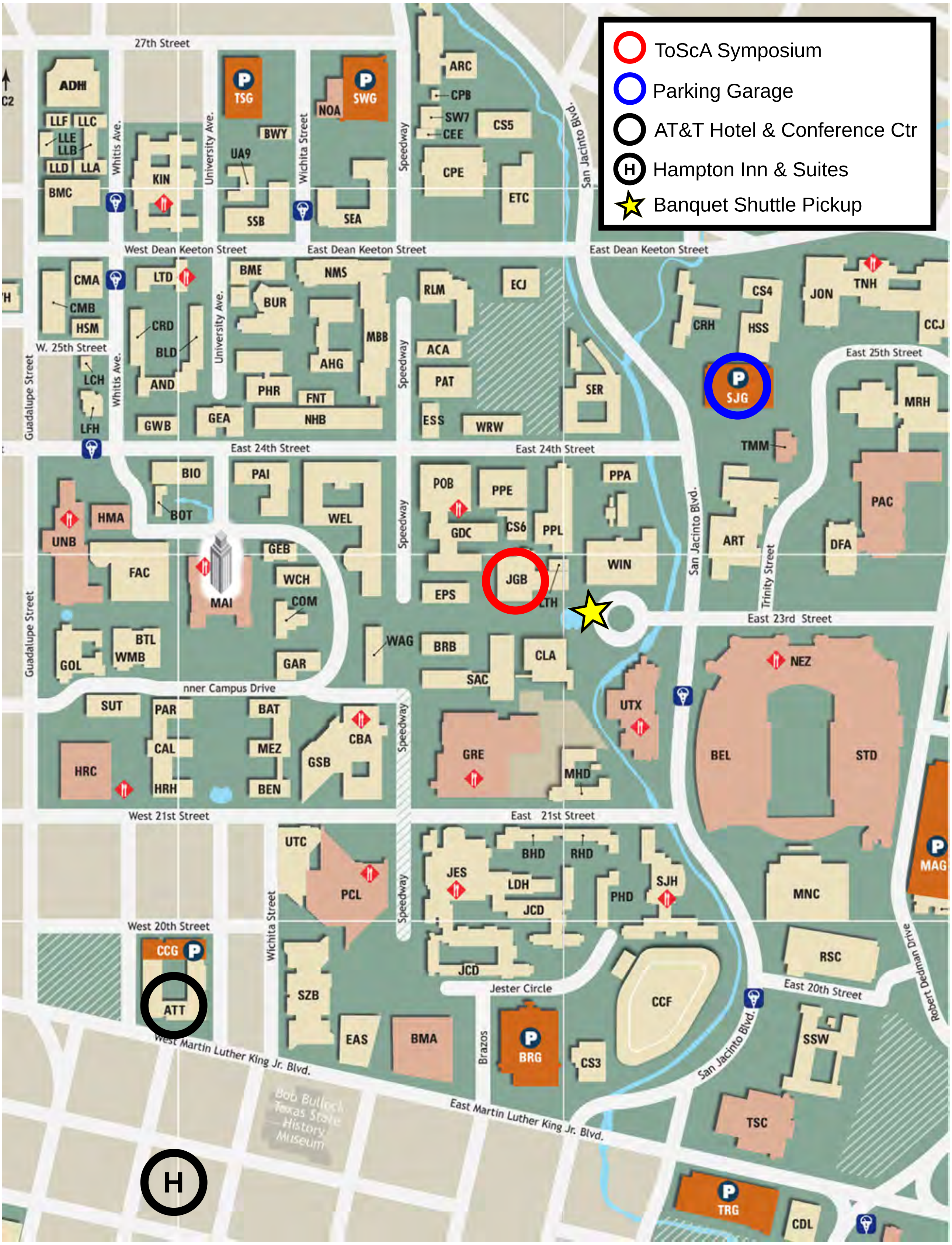
The Jackson School of Geosciences at UT Austin is among the most well-regarded geoscience programs in the world. The school includes the Department of Geological Sciences — one of the country's oldest geoscience departments — and two world-renowned research units, the Institute for Geophysics and the Bureau of Economic Geology. The school is home to the world's largest academic geoscience communities with almost 5,000 alumni, 650 graduate and undergraduate students, 56 faculty, 90 research scientists, 110 research staff and postdoctoral scientists and 140 support staff.

The Jackson School is both old and new. It traces its origins to a Department of Geology founded in 1888, but became a separate unit at the level of a college only on September 1, 2005. The school's formation resulted from one of the most generous gifts in the history of higher education, when the late John A. and Katherine G. Jackson bequeathed endowments and assets to the university presently valued at over $300 million.

TEXAS
The University of Texas at Austin

TEXAS Geosciences
The University of Texas at Austin
Jackson School of Geosciences

Campus Map



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Bob Bullock Texas State History Museum
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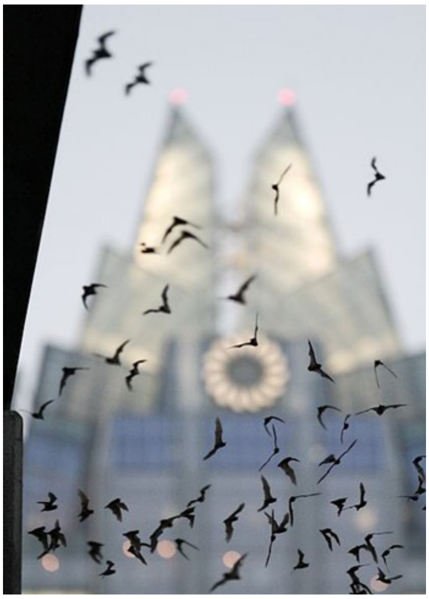
Current Activities in Austin



Congress Avenue Bridge Bats

Underneath the Ann W. Richards Congress Avenue Bridge lives the largest urban bat colony in North America. When they emerge in the evening during "bat season" (May-September) it's like a cloud flying toward the east. (www.austinot.com/guide-bat-season-in-austin)

Stories to Tell: Selections from the Harry Ransom Center

This exhibition of more than 250 items includes, among many other things, manuscripts of David Foster Wallace, Julia Alvarez, and Gabriel García Márquez, Henri Matisse's Jazz, Sir Arthur Conan Doyle's spirit photographs, and the hat that accompanied the green curtain dress worn by Vivien Leigh in Gone With The Wind. February – July 2017. The Harry Ransom center is located on the UT Austin campus. (www.hrc.utexas.edu/exhibitions/2017/storiestotell)

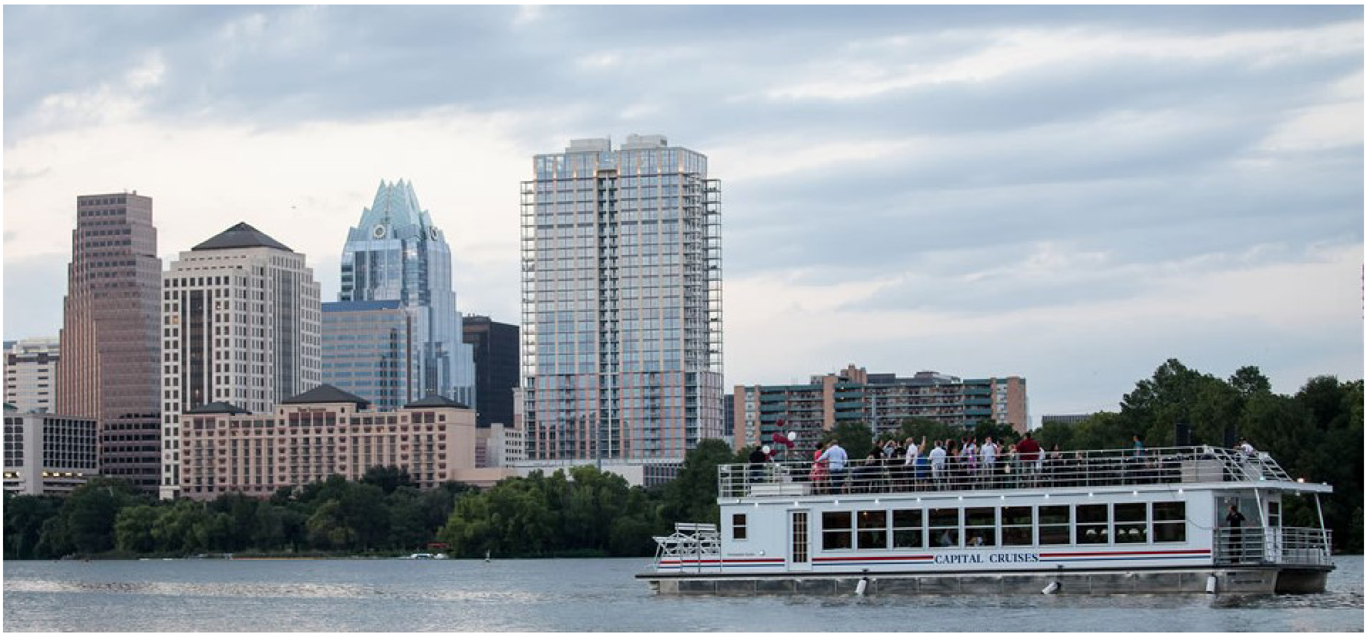
Barton Springs Pool

There's no better way to cool off from the Austin summer heat than to take a plunge in the iconic spring-fed pool that stays a cool 68-70 degrees year-round. Depths of the pool range up to 18' and it's surrounded by grassy areas on which patrons can lounge. Adjacent to the pool bathhouse is Splash!, an educational exhibit where patrons can learn about the history and biology of Barton Springs and the Edwards Aquifer that feeds it. Open daily 5 am – 10 pm (closed for cleaning Thursdays 9 am – 7 pm). (www.austintexas.gov/department/barton-springs-pool)

Symposium Banquet

Dinner Cruise

The Symposium Banquet will take place on Lady Bird Lake in downtown Austin aboard the M.V. Pride and Joy II. Enjoy Texas BBQ while watching the world's largest urban bat colony emerge from under the Congress Avenue Bridge! Wednesday evening we will have a drinks & posters session in the Jackson School and then board a private bus to the boat dock for the cruise. After dinner the bus will return to the AT&T Executive Education and Conference Center on the UT campus after a stop downtown for those who wish to continue their night out.



Post-Banquet Activities

After the banquet the bus will make a stop downtown at the Rainey Street district for those who might enjoy a post-dinner outing or drink. The Rainey Street neighborhood, a formerly sleepy area near the banks of Lady Bird Lake, has morphed into the latest hot spot for locals. Old bungalows have been fixed up and turned into bars and cocktail lounges with ample backyards and porches perfect for enjoying a drink on a summer evening. You can read more about Rainey Street here: https://tinyurl.com/ke7zjuj.

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Workshop Information

Two Pre-conference workshops will be held on 6 June 2017. The topics for the workshops are as follows:

Avizo introductory workshop including porosity analysis

Participants will be offered an introduction to data visualization, image processing & segmentation and the chance to try a new series of features for extending analyses performed on porous materials.

Avizo software currently offers advanced quantification features for computing volumes on each pore individually, including surfaces, shape characteristics, orientations, distance to the surface of the object, and distance to the nearest neighbor. The software's new features allow the study of the porous network as a whole and simplify the representation of the pores and the pore throats in the network. It enables filtering of the pores based on various criteria, along with the computation of measures such as permeability or tortuosity.

During the workshop, participants will use Avizo to perform data visualization, image processing, segmentation and a full analysis of a porous material.

Workshop outline

- General introduction to Avizo software
- What's new in Avizo 9.4
- Hands-on session
    - Introduction to workspace, modules & data visualization
    - Image processing & segmentation
    - Introduction to pore network modeling and new features

Duration: 2:30 h

VGSTUDIO MAX 3.0

This workshop will introduce you to CT data analysis and visualization using VGSTUDIO MAX. Volume Graphics will present typical workflows which are of special interest for the scientific community for the fast and precise analysis of voxel data: quantitative analysis options, segmentation, and advanced visualization techniques. VGSTUDIO MAX is the ideal tool for getting the most information possible from your data sets, whether acquired by laboratory X-ray CT, a synchrotron, with neutrons, or with another source. Use this special opportunity to speak personally with Volume Graphics experts!

Duration: 2:30 h

Program

Day 1: Wednesday 7 June 2017

09:00 - 09:30	Registration
09:30 - 10:00	Opening Remarks: Farah Ahmed, Chair; Jessie Maisano, Co-Chair; Richard Ketcham, UTCT Director; Sharon Mosher, Dean of the Jackson School
Session 1: Forensics (Session Chair: Timothy Rowe)	
10:00 - 10:30	Solving a very old, very cold case? Perimortem fractures in the famous fossil Lucy suggest that a high-energy impact event was responsible for her death. ***John Kappelman, The University of Texas, Austin, TX***
10:30 - 10:45	The use of industrial CT in forensic anthropology. ***Deborah Cunningham, Texas State University***
10:45 - 11:15	*Coffee Break*
Session 2: Multi-Modal Imaging (Session Chair: Lawrence Witmer)	
11:15 - 11:45	XROMM: a dynamic perspective on skeletal form. ***Stephen Gatesy, Brown University***
11:45 - 12:00	Combination of diffusible iodine-based contrast-enhanced computed tomography with measuring biodistribution and kinetics of 18F-FDG in extant birds: Implications on the evolution of the avian brain. ***Elizabeth Ferrer, American Museum of Natural History***
12:00 - 12:15	MicroComputed Tomography and X-ray diffraction of intact archeological human second metacarpal bones as a function of individuals' age at death. ***Stuart Stock, Northwestern University***
12:15 - 12:30	3D Virtual Astromaterials Samples: Combining high-resolution precision photography and X-ray computed tomography to create research-grade 3D models of NASA's Apollo lunar samples and Antarctic meteorite samples for curation, research, and education. ***Erika Blumenfeld, NASA Johnson Space Center***
12:30 - 13:30	*Lunch and Trade Exhibition*
Session 3: Educational Outreach (Session Chair: John Kappelman)	
13:30 - 13:45	eAnthro: Community engagement in developing online learning resources. ***Adrienne Witzel, The University of Texas, Austin, TX***
13:45 - 14:00	3D visualization in medical-student training. ***David Dufeau, Marian University College of Osteopathic Medicine***
Session 4: Geological Science I (Session Chair: Romy Hanna)	
14:00 - 14:30	Petrography in 3D: Why isn't everybody doing it? ***Richard Ketcham, The University of Texas, Austin, TX***
14:30 - 14:45	Improved grain screening and measurement using X-ray computed tomography: Applications to (U-Th)/He chronology. ***Emily Cooperdock, The University of Texas, Austin, TX***
14:45 - 15:00	Pore-scale X-ray CT Imaging of xenon hydrate in unconsolidated porous media. ***Xiongyu Chen, The University of Texas, Austin, TX***
15:00 - 15:30	*Coffee Break*
Session 5: Geological Science II (Session Chair: Emily Cooperdock)	
15:30 - 15:45	The Astromaterials X-Ray Computed Tomography Laboratory at Johnson Space Center. ***Ryan Zeigler, NASA, Johnson Space Center***
15:45 - 16:00	Utility of microCT for studying the fossil record of plants. ***Selena Smith, University of Michigan***
16:00 - 16:15	Using X-ray tomography to visualize Late Cretaceous–Early Paleogene plants of India. ***Kelly Matsunaga, University of Michigan***
16:15 - 16:30	CT scanning of deformed and folded cyclocystoids (Echinodermata) in siderite concretions from the Middle Ordovician of Morocco. ***James Sprinkle, The University of Texas, Austin, TX***
16:30 - 16:45	CT imaging of dinosaur footprints: Hidden topography and the origin of track diversity. ***Stephen Gatesy, Brown University***
16:45 - 17:00	*Lightning Talks*
17:00 - 18:00	*Drinks and Posters*
18:00	*Board bus to Banquet Cruise*
19:00 - 22:00	*Banquet Cruise*

Day 2: Thursday 8 June 2017

Session 6: Increasing Contrast (Session Chair: Jessie Maisano)	
09:00 - 09:30	Radiographic contrast enhancement in the present as a means of fleshing out the past: diceCT and vascular injection of extant birds and reptiles to better understand dinosaur biology. ***Lawrence Witmer, Ohio University Heritage College of Osteopathic Medicine***
09:30 - 09:45	Three-dimensional visualization of the embryonic murine chondrocranium using contrast-enhanced microCT. ***Timothy Ryan, The Pennsylvania State University***
09:45 - 10:00	High-resolution X-ray phase-contrast tomography of in vivo plant roots using contrast agent. ***Amin Garbout, The Natural History Museum (London)***
10:00 - 10:15	Contrast Enhanced CT as a method for identifying and quantifying parasites in invasive Anoles. ***Edward Stanley, Florida Museum of Natural History***
10:15 - 10:30	Tomography with energy dispersive x-ray diffraction. ***Stuart Stock, Northwestern University***
10:30 - 11:00	*Coffee Break*
Session 7: Data (Ownership, Repurposing, Management) (Session Chair: Richard Ketcham)	
11:00 - 11:30	Computed tomography data in collections-based research: A 25 year survey. ***Timothy Rowe, The University of Texas, Austin, TX***
11:30 - 11:45	MorphoSource: A virtual museum and digital repository for 3D specimen data. ***Julia Winchester, Duke University***
11:45 - 12:00	Exemplifying Digital Rocks Portal data management, visualization and simulation capability through a rough fracture permeability study. ***Christopher Landry, The University of Texas, Austin, TX***
12:00 - 12:30	Dragonfly Infinite Toolbox - a platform for customizing and sharing image analysis workflows. ***Mike Marsh, ORS***
12:30 - 13:30	*Lunch and Trade Exhibition*
Session 8: Materials Science (Session Chair: Mike Marsh)	
13:30 - 14:00	3D & 4D X-ray microscopy: Recent advances for materials science. ***William Harris, Zeiss***
14:00 - 14:15	Materials science applications of X-ray and neutron Interferometry/Tomography. ***Omoefe Kio, Louisiana State University***
14:15 - 14:30	Probing the microstructure of 3D-printed Carbon Fiber Composites. ***James Lewicki, Lawrence Livermore National Laboratory***
14:30 - 15:00	The new generation of YXLON's Smart Laboratory CT devices enabling high precision and maximum user friendliness. ***Andre Beerlink, YXLON***
15:00 - 15:30	*Coffee Break*
Session 9: Medical and Biological Science (Session Chair: Farah Ahmed,)	
15:30 - 15:45	X-ray computed tomography to quantify above- and below ground structures for an integrated understanding of plant form and function. ***Keith Duncan, Donald Danforth Plant Science Center***
15:45 - 16:00	Using iodine-contrasted µCT to facilitate imaging of structural brain defects. ***Ryan Gray, The University of Texas, Austin, TX***
16:00 - 16:15	Exploring the relationships between locomotor behavior and semicircular canal morphology in squamates: Preliminary results. ***Mike Polcyn, Southern Methodist University***
16:15 - 16:30	Impact and potential of computed-tomography in paleontology & archeology. ***Lauren Conroy, University of Chicago***
16:30 - 16:45	Using Micro-CT to unravel past bleaching events of Chagossian corals. ***Rebecca Summerfield, The Natural History (London)***
16:45 - 17:00	High resolution 3D imaging in biology and surgery: The role of Micro CT in the clinical and research lab. ***James Michaelson, Harvard Medical School and Massachusetts General Hospital***
17:00 -	*Final Remarks*

Oral Abstracts

Solving a very old, very cold case? Perimortem fractures in the famous fossil Lucy suggest that a high-energy impact event was responsible for her death

John Kappelman

Departments of Anthropology and Geological Sciences, The University of Texas, Austin, TX

Keywords: Lucy, Au. afarensis, perimortem, hires CT, vertical deceleration event

A.L. 288-1, "Lucy," is a young adult female of Australopithecus afarensis discovered at Hadar, Ethiopia, in 1974. She died 3.18 million years ago and is represented by much of her skeleton, making her among the oldest and most complete hominin fossils. Lucy was clearly bipedal when on the ground but some of her other anatomical features are also found in arboreal apes, suggesting that she might have combined arboreal climbing with terrestrial bipedalism; today, after more than 40 years of intensive study, Lucy remains at the center of a vigorous debate about the role, if any, that arborealism played in early human evolution. Initial study attempted to use medical CT but because she is heavily mineralized, the imagery is radiographically opaque. In 2008 I received permission to scan Lucy at UT Austin's hires CT lab. Lucy's skeleton preserves the typical breaks seen in most fossils, and all were originally attributed to postmortem damage. However, we identified a subset of breaks that are compressive bone-into-bone fractures at the major joints, preserving tiny bone fragments with sharp edges and no sign of healing. These fractures can be matched with those found in victims of a "vertical deceleration event," an impact following a fall from considerable height. We digitally segmented the fractured bones and used Maya to reconstruct the elements and animate the etiology of the injuries. We investigated various alternatives and conclude that a fall from considerable height, probably out of a tall tree, was most likely responsible for these high-energy fractures.

The use of industrial CT in forensic anthropology

Deborah L. Cunningham[1], Daniel J. Wescott[1], Devora S. Gleiber[1], Angi M. Christensen[2], and Michael A. Smith[2]

[1]Forensic Anthropology Center, Department of Anthropology, Texas State University, San Marcos, TX
[2]Federal Bureau of Investigation Laboratory, Quantico VA

Postmortem computed tomography (PMCT) is increasingly being used to supplement the forensic autopsy, but the use of industrial CT systems in forensic anthropological investigations is still rare. Currently, the Federal Bureau of Investigation (FBI) Laboratory and Forensic Anthropology Center at Texas State (FACTS) both utilize the North Star Imaging ® X5000 CT scanner in postmortem assessments of skeletal remains for forensic and research purposes. This unit is marketed primarily for nonmedical, industrial applications but is readily adaptable for use in anthropological investigations that require nondestructive and noninvasive external and internal inspection of items. Forensic anthropological applications of industrial CT include, but are not limited to, preservation of evidence, documenting features for identification, analysis of skeletal trauma and disease, assessment and documentation of biological parameters, production of 3D printed replicas, and research on bone density and microstructure. Skulls and other bones with trauma and taphonomic damage, especially those with some soft tissue retention, can be scanned prior to processing to record the original damage and specimen integrity and to provide information about the cause and manner of death. The images can be transferred to other investigators or used for revaluation at a later date. High resolution CT reconstructions are also ideal for visual inspection of bone and comparison with antemortem records for identification. Visualization can be improved by adding color and transparency with CT software. For trauma cases with complete or comminuted fractures, replicas based on CT images can aid in physical reconstruction or be used for testimony and second opinions without jeopardizing the chain of custody. Virtual images are ideal for court presentation because they provide accurate representation of the original specimen, can be manipulated in virtual space, but may trigger less of an emotional response in the

jury members than autopsy photographs. Another significant advantage of this type of machine in a setting such as the FBI Laboratory and an academic laboratory such as FACTS is that, unlike a medical CT that is configured and dedicated to one or a few specific purposes, the machine has many other forensic and research applications. In the FBI Laboratory, the device supports forensic examinations of manufactured products, explosive devices, electronics, and firearms, as well as forensic anthropology. At Texas State University the system is employed to image and examine the microstructure of bone as well as archaeological, paleontological, and geological specimens. This ensures a high utilization rate and more readily justifies the costs of its operation and maintenance. The use of more versatile industrial machines may be more cost effective for a laboratory to purchase, especially in cases where the device can serve multiple disciplines thus reducing the potential need for multiple devices.

This research is supported in part through instrumentation funded by the National Science Foundation under Grant NSF:MRI 133804.

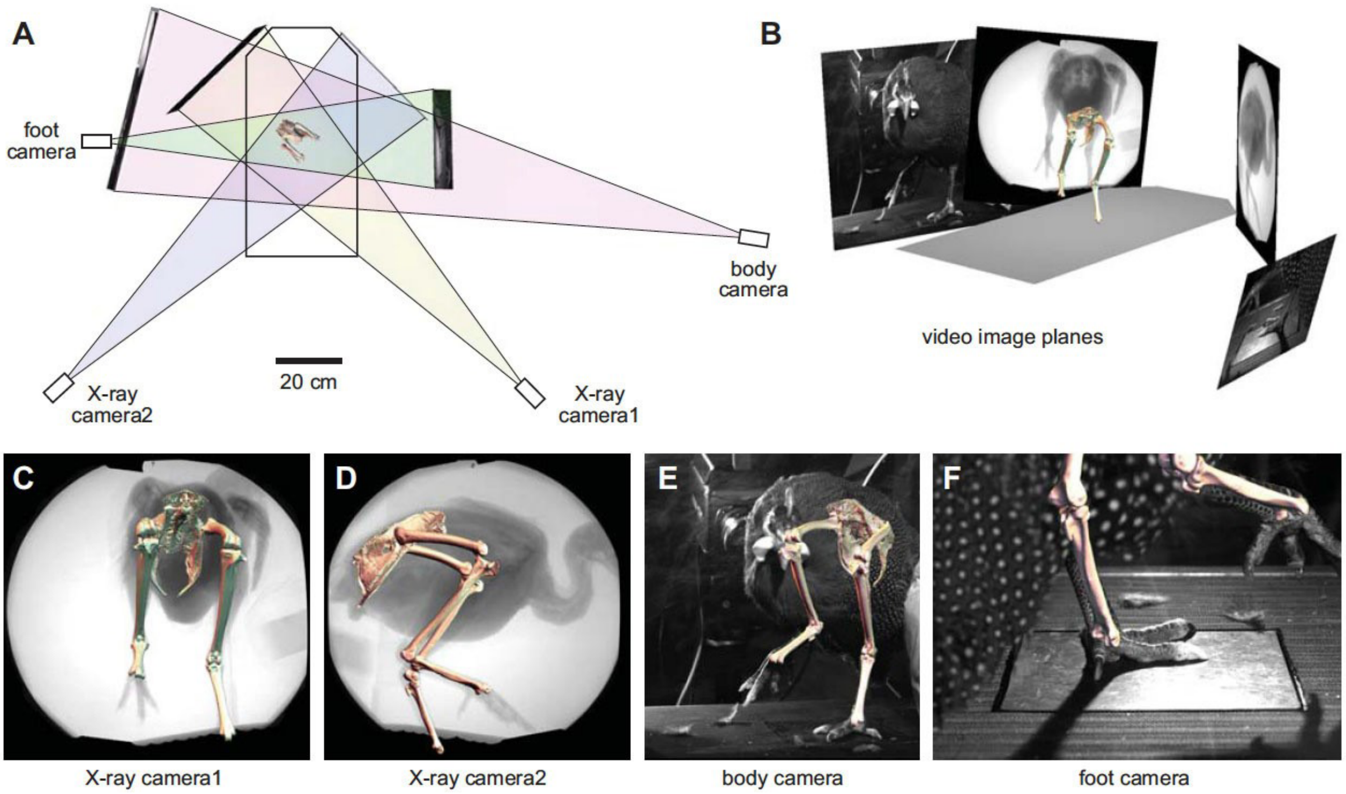
XROMM: A dynamic perspective on skeletal form

Stephen M. Gatesy and Elizabeth L. Brainerd

Department of Ecology and Evolutionary Biology, Brown University, Providence, RI

Keywords: XROMM, animation, motion, skeleton, vertebrate

CT imaging offers ever-growing opportunities to image and model vertebrate anatomy in 3-D. X-ray reconstruction of moving morphology (XROMM) is a set of methods for combining bone shape data from CT with bone motion data from X-ray videos. Variations include marker-based XROMM, in which radio-opaque markers are surgically implanted into skeletal elements, and markerless XROMM, which includes manual scientific rotoscoping and semi-automated bone model registration methods. The result is a precise and accurate XROMM animation of 3-D bone meshes moving in 3-D space from which six degree of freedom joint kinematics and other quantitative data can be extracted. Over the past nine years, researchers have used XROMM to study in vivo skeletal motion in numerous behaviors and species including: terrestrial locomotion of turtles, alligators, birds, rats, and dogs; arboreal locomotion of sloths; jumping in frogs and humans; feeding in fish, geckos, ducks, and pigs; flight in birds and bats; lung ventilation in lizards; and track formation in dinosaurs. We will present a brief history of XROMM, describe basic workflows, and show animated examples from a variety of projects to demonstrate the novel insights that skeletal dynamics can provide.



Combination of diffusible iodine-based contrast-enhanced computed tomography with measuring biodistribution and kinetics of 18F-FDG in extant birds: Implications on the evolution of the avian brain

Elizabeth Ferrer[1], Paul Vaska[2], Michael Salerno[2], David Ouellette[2], Shouyi Wei[2], Gabriel Bever[3], Paul Gignac[4], and Amy Balanoff[3]

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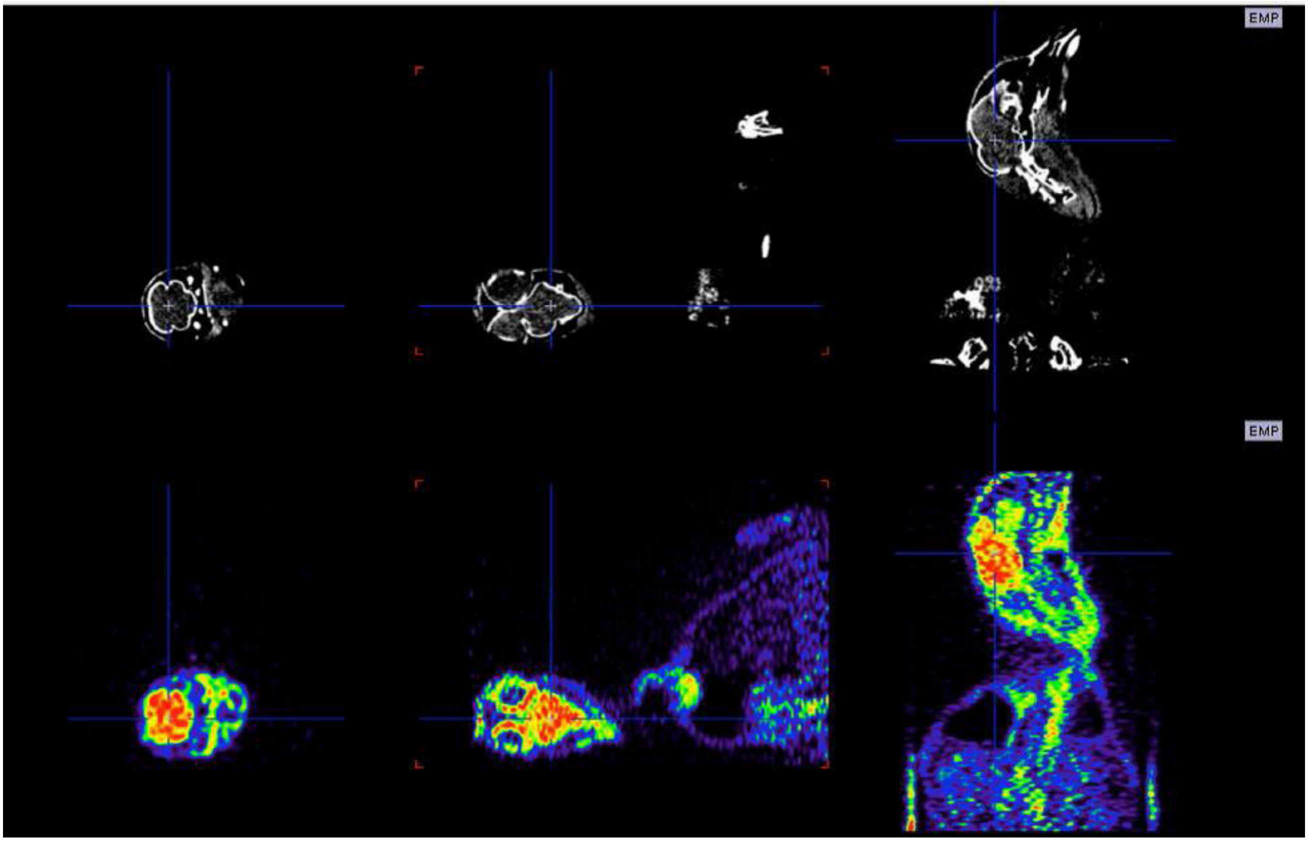
[2] Stony Brook University, Stony Brook, NY
[3] Johns Hopkins University, Baltimore, MD
[4] Oklahoma State University, Tulsa, OK

Keywords: Aves, PET, CT, brain evolution

Despite intense research, there is still much to learn about the evolution of birds, one of only three vertebrate groups to achieve powered flight. Most research has focused on the postcranial skeleton and epidural appendages during the transition from non-avian dinosaurs to birds, but modifications of the neuroanatomical architecture are also expected. Little is known of the neurological processing necessary for flight. In our research we aim to understand the evolution of the avian brain using a combination of diffusible iodine-based contrast-enhanced computed tomography(diceCT), biodistribution and kinetics of 18F-FDG, and PET scanning in extant birds. This work will underpin studies on the neuroanatomical nuclei most active during behaviors including flight because 18F-FDG builds in regions of high metabolic activity. Initially we injected 18F-FDG into anesthetized starlings and pigeons then performed dynamic PET imaging starting at injection using the Inveon-PET/CT system. As a fraction of injected dose, the brain often reached a concentration similar to rats (~0.6% per cc). Birds were pedestal flight trained, and injected with 18F-FDG before flight. Serial blood sampling was done to measure the plasma input function, indicating that peak brain uptake of 18F-FDG occurs at around 15 minutes, which was the total time the birds were flown before scanning. In the future we plan to expand methodology to additional birds to see how active nuclei vary across Aves, providing a firmer foundation on understanding the neurological capabilities necessary for powered flight and gaining insight into their shape and function at their origin along the avian stem.



MicroComputed Tomography and x-ray diffraction of intact archeological human second metacarpal bones as a function of individuals' age at death

Stuart R. Stock[1], Jun-Sang Park[2], Malene Laugesen[3], Simon Mays[4], Jonathan D. Almer[2], Henrik Birkedal[3], and Carmen Soriano[2]

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[3] iNANO and Dept. of Chemistry, Aarhus University, Aarhus, Denmark
[4] Analysis and Investigation Division, English Heritage, Portsmouth, United Kingdom

Keywords: x-ray diffraction, microCT, bone, archeology

Bones recovered from archeological sites provide information on past human health, and destructive sampling is often not an option, making x-ray methods invaluable. This paper uses two high energy x-ray methods to study human second metacarpal (Mc2) bones from Roman (Ancaster) and from medieval (Wharram Percy) Britain. MicroComputed Tomography (microCT) and position resolved x-ray scattering (wide angle – WAXS – and small angle – SAXS) provide quantitative data on six Mc2 from each site with two Mc2 from each of three age (at death) cohorts and on a modern Mc2 and two synthetic hAp phantoms.

Laboratory microCT imaged trabecular bone, and synchrotron microCT (2-BM, Advanced Photon Source - APS) imaged cortical bone from these Mc2. A series of WAXS and SAXS patterns covering the cross-section of these Mc2 and phantoms were collected simultaneously with a 50 μm wide beam at 1-ID, APS. Rietveld refinement was applied to the WAXS patterns, and cAp lattice parameters and crystallite size and microstrain determined. From SAXS, collagen D-period was quantified.

We seek to answer the following questions: 1) How does the microCT and scattering data correlate in defining bone "quality"? 2) How much has diagenesis altered the bone material and changed quantities measured by x-ray scattering (cAp lattice parameters; crystallite size, microstrain; collagen D-period)? 3) If diagenetic changes are minor or non-existent, do the above quantities change with age in Roman and medieval era populations, and are these changes similar to those observed for bone from modern sedentary populations?

3D Virtual Astromaterials Samples: Combining high-resolution precision photography and X-ray computed tomography to create research-grade 3D models of NASA's Apollo lunar samples and Antarctic meteorite samples for curation, research, and education.

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Keywords: samples,virtual samples, high-resolution photography, X-ray computed tomography, NASA

NASA's current and future astromaterials collections are both scientifically and culturally significant, requiring unique conservation strategies that need to advance as current technological capabilities improve and as sample accessibility demands increase. Research-grade 3D Virtual Astromaterials Samples (VAS) will increase accessibility and visibility of these collections for researchers, educators and the public worldwide.

Since 2013, our interdisciplinary team has been developing a method to create virtual 3D reconstructions of astromaterials samples that are a fusion of two state-of-the-art data sets: X-ray Computed Tomography (XCT)-derived internal composition data and Structure-From-Motion (SFM) Photogrammetry-derived high-fidelity external textured polygonal models.

Our initial efforts in fusing these two data sets to achieve the 3D VAS have been successful. The process computes and applies the six degrees-of-freedom transformation of the SFM-derived textured external model of the sample into the coordinate system of an XCT-derived isosurface model of the same sample. This method combines both datasets into a common coordinate system, providing the means to produce the single 3D VAS.

Our research demonstrates that research-grade VAS are beneficial in preserving for posterity a precise 3D reconstruction of the sample prior to sub-sampling, which greatly improves documentation practices, provides unique and novel visualization of the sample's features, offers scientists a preliminary research tool for targeted sub-sample requests, and is a visually engaging interactive tool for bringing astromaterials science to the public. All 3D VAS models and original data will be served on NASA's Astromaterials Acquisition and Curation website (https://curator.jsc.nasa.gov) beginning in 2019.

eAnthro: Community engagement in developing online learning resources

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Keywords: 3D printing, STL, public, education, collaboration

The eAnthro Project is a suite of online learning resources that dates back to the beginning of the web. It offers virtual libraries and collaborative learning exercises otherwise not easily available to a diverse community of K-Grey learners. Our initial efforts included eSkeletons.org, a site of skeletons combining color images, 3D movies, animations, and interactive overlays; and eLucy.org, a site about the most famous fossil on the planet presented in a rich comparative context with information on the latest research. Continuing efforts are cognizant that the bounty of research results and pedagogical materials is now beyond what any one team can reasonably author, and instead we offer a repository for contributions from engaged users who retain authorship. For example, eFossils.org was designed as a "collaboratorium," a web tool built on a generic template that permits the research community to collaborate on large-scale problems. Future iterations of our existing websites will include similar contribution templates, including an STL library, so that users who assist in building the eAnthro websites become owners, and their investment ensures sustainability and vitality.

3D visualization in medical-student training

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Keywords: medical education, diagnostic imaging, 3D visualization, 3D printing, stereolithography, sectional imagery, anatomy, pathology, CT, MRI, histology

Visualizing the spatial relationships of anatomical features, gross pathologies, and diagnostic findings is a fundamental part of the training of medical students and other learners in health-professions curricula. But to what extent can we augment the conventional training opportunities (e.g. Gross dissection, interpretation of sectional imagery, interpretation of histological sections) with 3D enhanced visualizations of anatomic, histologic, and diagnostic data-sets? Here we present a case study of medical-students at Marian University College of Osteopathic Medicine utilizing 3D visualization and printing techniques as part of a summer training opportunity. Medical students, in the summer between their first and second year of medical school training, self-identified an interest in the interpretation of sectional imagery. These students were then encouraged to design a project with the aim of presenting a 3D visualization of an anatomic or pathologic study that could be better understood in a 3D format than conventional imaging formats. The students also identified the target audience for these studies—these included student-doctors, medical residents, and clinical patients. Case studies the students completed included visualizations of maxillofacial surgical interventions, pediatric cardiac defects, neurological tracts, cerebral basal ganglia, and paranasal sinuses, among others. The resulting 3D interpretations were then presented as either 3D prints (utilizing stereolithography), YouTube videos, interactive 3D PDF files, or some combination of these media. It is possible to develop case studies to a high degree of maturity during a summer program. The next step in this study is to identify the efficacy of these presentations in various learning environments.

Petrography in 3D: Why isn't everybody doing it?

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Keywords: meteorite, chondrite, diamond, textural analysis, pseudomorphc

An early critique of X-ray CT for geological applications was that it only produced "pretty pictures", and subsequently a great amount of effort has been expended in developing the computational tools to extract quantitative data from voxel data sets. However, within those "pretty pictures" lie underexplored opportunities for changing the way we do geoscience by helping us think in new ways. This talk will discuss two examples of the power of high-resolution X-ray CT for amplifying geological intuition. In the first, scans of CM chondrite Murchison reveal the presence of a deformation fabric in both the chondrules and their fine-grained rims (Hanna et al., 2016; Hanna and Ketcham, in prep). These observations, and the ability to quantify them, led to new insights into solar system processes ranging from the turbulence of the solar nebula to impact-driven compaction and aqueous alteration on asteroid surfaces. In the second, scans of carbonado, an enigmatic polycrystalline diamond variety, and inspection of its inclusion and pore textures provides a multitude of fresh clues on its origin. New observations include pseudomorphs of now-absent companion phases, fractures healed by diamond growth, mm-scale domains of dramatically different pore structure, and preferred orientation of pores across these domains. These examples of the power of 3D observation combined with simple geological insight and imagination point to the tremendous potential for scientific discovery with more widespread dissemination and utilization of CT data, and the importance of lowering the technical, educational, and financial barriers to it.

Improved grain screening and measurement using X-Ray Computed Tomography: Applications to (U-Th)/He chronology

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Keywords: thermochronology, opaque minerals, reduced uncertainties

(U-Th)/He thermochronology is a powerful, and widely applied, tool to date upper crustal geologic processes active from near surface temperatures up to ~300°C. As with all mineral-based chronological systems, the technique has several fundamental requirements that must be met to garner meaningful results. This includes analysis of pure mineral phases clean of inclusions, fractures or intergrowths; and precise surface area or volume measurements to calculate FT corrections and diffusion domain size. The typical tool to account for these requirements is an optical microscope with a camera attachment. However, this tool is severely limited for screening the internal character of opaque minerals (e.g., oxides, sulfides), and for precise surface area or volume measurements for irregularly shaped mineral grains (e.g., conodonts, fragments). High Resolution X-Ray Computed Tomography (CT) is an affordable and efficient tool to provide non-destructive, 3-D visualization of mineral grains, provide first-order textural and compositional information, and allow for precise 3-D measurements of entire grains, regardless of shape. Therefore, the use of CT in concert with (U-Th)/He can expand the technique to different mineral phases, and reduce uncertainties associated with grain measurements.

Pore-scale X-ray CT imaging of xenon hydrate in unconsolidated porous media

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Keywords: hydrate, unconsolidated porous media, micro-CT, pore-scale image, crystallization, dissociation, wettability

Methane hydrate in permafrost and oceanic sediments is both a potential energy resource and a liability to global warming. Understanding pore-scale mechanisms of hydrate formation, growth, and dissociation is critical to producing natural gas from hydrates and preventing unwanted methane release from hydrate dissociation to the atmosphere. This study shows X-ray microtomography monitoring of Xenon hydrate formation, growth, and dissociation in hydrophilic and hydrophobic porous media. Xenon gas has a similar van der Waals radius to that of methane (2.06 Å for methane and 2.16 Å for Xenon). Figure 1 gives an example of hydrate crystallization in water-

wet sand pack. Higher gray-scale number (more white) means higher X-ray attenuation. It can be seen that, after 19 days of crystallization, Xenon hydrate (white) and Xenon gas (gray) coexist in the pores and no water is found in the pores. This is because water is completely consumed to form hydrate in the excess gas condition.

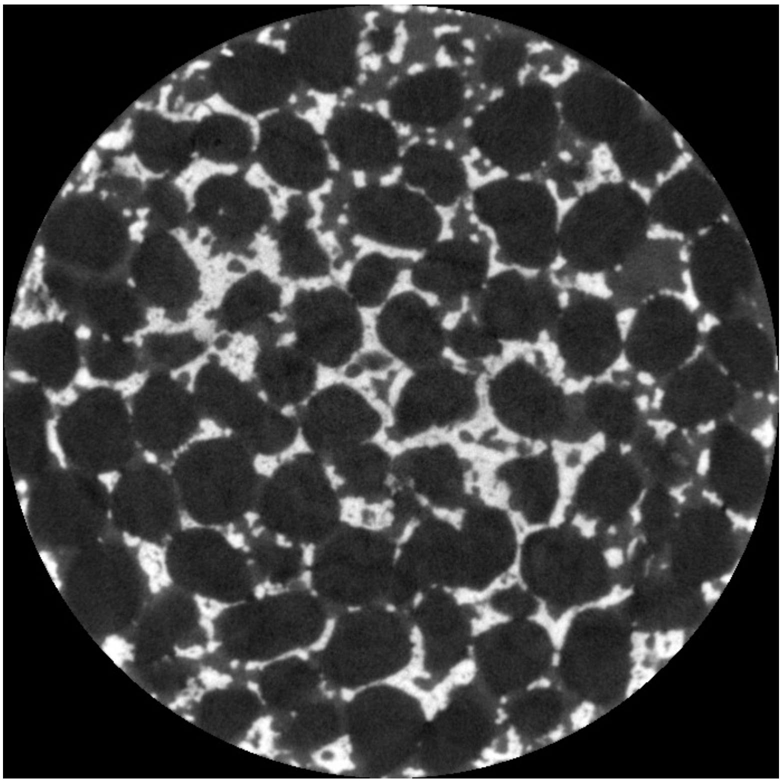

Figure 1. Pore-scale image of sand pack (black) after 19 days of hydrate crystallization. Steady state has reached and the pores are saturated with Xenon gas (gray) and Xenon hydrate (white). The resolution is 12.42 um and the diameter of the circle is 8.61 mm.

The Astromaterials X-Ray Computed Tomography Laboratory at Johnson Space Center

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Keywords: moon, meteorites, geology, curation

The Astromaterials Acquisition and Curation Office at NASA's Johnson Space Center is home to NASA's astromaterials sample collections. The primary goals of the curation office are to maintain the long-term integrity of the samples and ensure that the samples are distributed for scientific study in a fair, timely, and responsible manner, thus maximizing the return on each sample. Part of the curation process is planning for the future, thus we also perform fundamental research in advanced curation initiatives. Advanced Curation is tasked with developing procedures, technology, and data sets neces-sary for curating new sample collections, or getting new results from existing sample collections. As part of these advanced curation efforts, we are installing a Nikon XTH 320 micro-XCT system in JSC curation with four interchangeable X-ray sources, a large-area detector, and a heavy-duty stage. These instrument characteristics will allow us exceptional flexibility to analyze a wide range of sample sizes. Also, the penetrative nature of the XCT scans allows for astromaterials samples to be analyzed within sealed low-density containers, preserving the pristinity of the samples. We plan to begin systematic scanning of the Apollo and Antarctic Meteorite sample suites in order to non-destructively map out the phases and voids within samples (being mindful of potential contamination issues related to X-ray flux). These scans will be made available to the scientific public via the curation website and newslet-ters. We anticipate that the data from these micro-XCT scans will allow scientists to better answer open questions in planetary science.

Utility of microCT for studying the fossil record of plants

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Keywords: paleobotany, biodiversity, collections, Cretaceous, Paleogene

Fossils provide critical data to understand broad patterns of biodiversity, biogeography, and evolution over geological time scales. Much of this information depends on an accurate placement of fossils within a phylogenetic framework and comparison between localities and preservation states. Synchrotron-based or industrial X-ray micro-computed tomography (microCT) is a particularly useful tool for studying fossil plant material because it is non-destructive, rapid, provides both 2D and 3D morphoanatomical data, and can enhance collections by archiving specimen data in case of compromised integrity and enabling virtual sharing and examination of material. MicroCT has been used on variety of fossil materials including charcoalifications, permineralizations in carbonates and cherts, and compression fossils. "Virtual taphonomy" can be accomplished by using "virtual dissections" or "virtual fossilization" to produce hypotheses of expected morphologies from modern or fossil organs by revealing cryptic morphologies and providing "search images" so that we may recognize fossils correctly. Examples from Cretaceous-Paleogene paleobotanical localities including the Deccan Intertrappean Beds (India), London Clay (UK), and Messel (Germany) demonstrate how application of microCT has helped understand the paleobiodiversity at these localities by providing new data on internal structures allowing determination of fossil affinities. Studies of specific groups, like the Zingiberales (gingers, bananas, and relatives), illustrate the power of microCT in assembling large comparative datasets to place critical fossil taxa in a phylogenetic context. MicroCT is a valuable tool for paleobotanical studies, enhancing to our ability to study museum specimens and build comparative datasets to elucidate broader patterns of diversity and evolution from the fossil record.

Using X-ray tomography to visualize Late Cretaceous–Early Paleogene plants of India

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Keywords: fossil, fruit, monocot, India

Silicified plant fossils of the Late Cretaceous–early Paleogene Deccan intertrappean beds of India have been studied for over a century using traditional methods of serial grinding, thin sectioning, and peeling (e.g. cellulose-acetate peels). While data obtained using these techniques are usually sufficient for resolving morphology and taxonomic affinities, these destructive techniques are not suitable for very large or small specimens or for many museum specimens. In addition, reconstructing the three-dimensional (3D) morphology of particularly complex structures can be especially challenging. To better understand the floral biodiversity in India at the Late Cretaceous, we are using X-ray micro-computed tomography (μCT) to study several problematic fossils. Scan quality is variable between specimens and fossil localities, with some chert specimens yielding higher contrast in μCT scans than others. Nevertheless, μCT has proved valuable for resolving the 3D morphology of several fossil reproductive structures, including Enigmocarpon, Tricoccites, and Viracarpon. One of these, Viracarpon, has been the subject of much disagreement over its morphology and taxonomic affinities. 3D reconstructions based on μCT scans aid in visualizing the complex external morphology of these fruits, resolving the conflicting interpretations of previous researchers. Moreover, comparisons between Viracarpon and fruits of Coahuilocarpon from the late Campanian of Mexico provide intriguing insights into the biogeography of Viracarpon. Our research indicates that μCT is an efficient and viable method of studying silicified fossil floras, with some advantages over traditional techniques, and continues to be invaluable for reexamining museum specimens for which nondestructive study is essential.

CT scanning of deformed and folded Cyclocystoids (Echinodermata) in siderite concretions from the Middle Ordovician of Morocco

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Keywords: cyclocystoids, Ordovician, Morocco, CT scanning, thecal, folding

Cyclocystoids are a small, extinct, Paleozoic class of flattened, circular, bottom-living echinoderms. They have a thin, flexible, oral disk of small plates, surrounded by a circular ring of domed ossicles often with small cupules, and a peripheral skirt of tiny plates. The living orientation and life mode of cyclocystoids are still controversial.

We used CT scanning to study a new cyclocystoid genus and species preserved in ellipsoidal siderite concretions from the Middle Ordovician of Morocco. Weathering of the enclosing concretions has dissolved the enclosed echinoderm calcite plates, leaving a thin, air-filled cavity surrounded by tough but porous clastic matrix. This thin cavity represents a plane of weakness when the concretion is broken open into two counterparts representing the upper and lower surface molds of the flattened cyclocystoid. Rounded concretions contain nearly complete and well preserved cyclocystoid specimens, but more irregular concretions contained imperfect specimens that had been injured during life, deformed when buried alive by catastrophic storms or sediment slumps, or disarticulated while partly exposed on the shallow sea floor.

CT scanning of two reassembled irregular concretions revealed that they contained cyclocystoids that had been folded double through the thin central disk, breaking the more resistant ring ossicles at their sutures. The two cyclocystoid specimens were also folded in opposite directions, one with the domed ring ossicles folded outward, the other with the domed ring ossicles facing inward. The larger specimen was more disarticulated than the smaller one, indicating more severe deformation when folded. This is the first report of folding in cyclocystoids, a feature not seen in similar-shaped edrioasteroids that attached more tightly to their substrate.

CT imaging of dinosaur footprints: Hidden topography and the origin of track diversity

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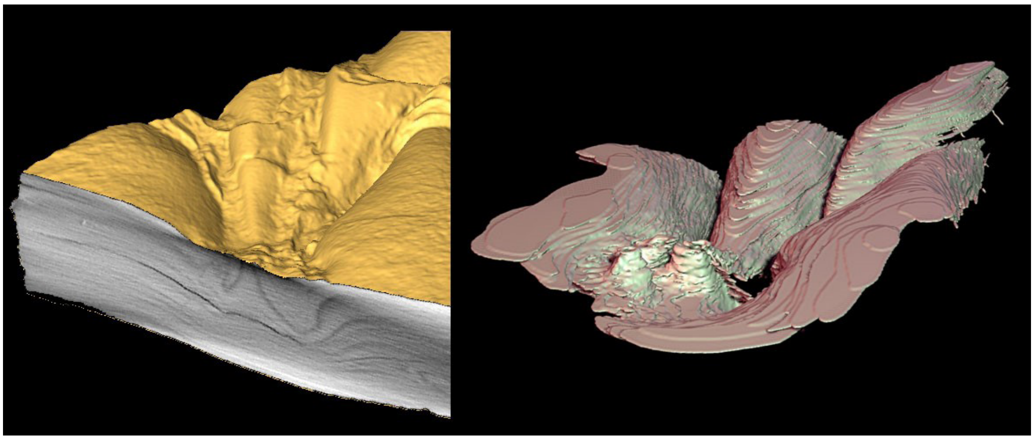
Keywords: paleontology, fossil, dinosaur, footprint, track

Dinosaur footprints are trace fossils documenting the interaction of live animals with deformable substrates. Some tracks are relatively accurate molds of the foot, but most are not. Factors such as substrate consistency and foot motion are known to give rise to disparate track morphologies that may differ significantly from static pedal anatomy. Although typically viewed as surfaces, any given track is a sample of a broader, often hidden, 3-D phenomenon. Some specimens of deep tracks can be split into multiple slabs, revealing evidence of foot movement into and out of the sediment volume. We used CT imaging to reconstruct internal surfaces of deep tracks from the Early Jurassic (~200 MYA) of the Connecticut Valley. Our first glimpse inside these fossils reveals that natural breaks, mechanical splitting, and subsequent preparation have damaged most exposed surfaces significantly. In particular, elevated features documenting foot withdrawal were either too fragile to survive or were mistakenly removed. Such topographic structures are key to understanding how deep tracks formed and explaining the origin of footprint disparity. CT data enable us to more clearly observe the results of foot-sediment interactions than is possible from exposed surfaces alone.



Radiographic contrast enhancement in the present as a means of fleshing out the past: diceCT and vascular injection of extant birds and reptiles to better understand dinosaur biology.

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Extinct vertebrates tend to preserve just the hard parts like bones and teeth. Time has stripped the biology from the fossils, challenging our ability to understand the function, physiology, and behavior of extinct organisms. Studying the soft tissues of the extant outgroups that phylogenetically bracket the extinct taxa has provided a window into the past, with successes being achieved using dissection and other traditional techniques. However, the jump to 3D modeling and simulation-based hypothesis testing requires anatomical detail that standard CT cannot fully provide due to a lack of soft-tissue contrast. As in a clinical diagnostic context, the use of contrast media such as iodine and barium dramatically increases anatomical resolution. Our team has been using diffusible iodine-based contrast-enhanced computed tomography (diceCT) to stain and visualize a diversity of soft-tissue systems (e.g., muscles, nerves, brain, epithelia, glands) in the heads of extant diapsids. Likewise we have been using differential-contrast dual-vascular injection (DCDVI) to explore arterial and venous circulation. These techniques have allowed us to clarify the relationships between soft and hard tissues using µCT and diagnostic (hospital) CT, providing better osteological correlates for restoring soft-tissue attributes of fossils. Examples include studies of the evolution of (1) the nasal salt gland that test hypotheses on the ecology of extinct birds, (2) the vascular system that sheds light on the physiological evolution of thermal strategies in dinosaurs, (3) the nasal epithelium that allows airflow to be modeled, and (4) the brain and neural tissue that provides insight into sensorineural evolution, among others.

Three-dimensional visualization of the embryonic murine chondrocranium using contrast-enhanced microCT

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Keywords: chondrocranium, phosphotungstic acid, contrast enhanced microCT

The chondrocranium is that part of the endoskeleton that protects the brain and three principal sense organs. Chondrocranium development precedes that of the dermatocranium during embryogenesis. Preliminary data from whole mount staining of mouse embryos for cartilage (alcian blue) and bone (alizarin red), in conjunction with histological observation of sectioned specimens, demonstrate spatiotemporal associations and coordinated development of the chondrocranium and dermatocranium, suggesting their dynamic interaction during skull formation. However, our hypotheses about the function of the chondrocranium as a scaffold for dermatocranium development require precise 3D reconstructions of the embryonic chondrocranium, as well as visualization of the 3D relationship between embryonic cranial cartilage and forming dermatocranial bones (e.g., frontal, parietal). Here, we use contrast-enhanced microCT to characterize and visualize the developing murine chondrocranium. Embryonic mice aged E14.5-E17.5 were prepared for scanning using a protocol developed to enhance contrast of non-mineralized embryonic tissues using phosphotungstic acid (PTA). Each embryo was mounted in agarose within a small vial and microCT scanned on the GE v|tome|x L300 scanner in the Center for Quantitative Imaging at Penn State with voxel dimensions between 1 and 3 microns. Cartilage was segmented using automated deep learning algorithms and visualized in 2D and 3D. These approaches and associated findings have immediate implications for understanding the integration and evolution of embryonic cranial modules using the developing laboratory mouse, currently the most experimentally accessible mammalian model.

High-resolution X-ray phase-contrast tomography of in vivo plant roots using contrast agent

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Keywords: phase contrast, contrast agent, plant, in vivo

Roots have an extreme impact on soil properties, and understanding their development and interactions with soil parameters are essential toward successful crop management. Several techniques such as root washing have been used to investigate root developments but most of them are destructive or requires complex sample preparation. An alternative technique is X-ray computed tomography (μCT), a non-destructive quantitative technique that have been used widely to provide new parameter insights of soil – root - water interactions. However, present μCT systems typically show limited spatial resolution and/or long exposure times making the absorption-contrast 3D imaging techniques not appropriate to image soft tissue such as roots.

Plant seedling roots comprise of elements with low atomic numbers and low density, at high photon energies, therefore the absorption contrast is weak thus making the segmentation of roots tedious.

We propose to improve absorption contrast, by staining pea seeds using high-atomic-number contrast agent i.e. Phosphotungstic Acid (PTA) in a concentration that will not be lethal for the seedling.

We applied PTA contrast agent to each seedling by staining the seeds in a Petri dish filled with 5 ml of 1% PTA five days before transferring them in a tube filled with sieved soil (sandy loam soil). The seedlings were then scanned at different development stages over a period of 2 weeks using the Versa 520 (Carl-Zeiss).

Combining the use of contrast agent and phase contrast propagation method permitted to achieve better contrast of roots.

Contrast Enhanced CT as a method for identifying and quantifying parasites in invasive anoles

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Parasite screening of herpetological museum specimens usually focuses on either external or intestinal parasites, and the latter requires significant destructive processing of the specimen. We employed a recently developed imaging technique (Diffusible Iodine Contrast Enhanced Computed Tomography, or DICECT) as a novel, non-destructive method for parasite screening. A series of specimens of *Anolis carolinensis* and *A.sagrei* were soaked in 1.25% Lugol's iodine and scanned using a Phoenix Vtome|x M CT scanner. This produced high resolution tomograms (serial sections) of the specimens soft tissues, revealing a high number of intestinal (nematode) and intramuscular (trematode) parasites. This technique offers a way of comprehensively screening museum specimens for parasites and recovers a range of novel, quantitative metrics of parasite load; the fact that endoparasites can be visualized in situ, for example, allows us to record of position and orientation of individual parasites, the overall parasite diversity and distribution, and the overall volume of parasites. This technique facilitates a number of interesting research questions, including how parasites respond to invasive species, and how parasite loads change annually, or over longer periods. As this technique is reversible (iodine specimens can be de-stained by soaking them in ethanol) even rare, otherwise unavailable museum samples can be fully screened for parasites.

Tomography with energy dispersive x-ray diffraction

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Keywords: energy dispersive x-ray diffraction, tomography, bone, hydroxyapatite, synchrotron x-radiation, crystallographic phase mapping

X-ray diffraction can be used as the signal for tomographic reconstruction and provides a cross-sectional map of the crystallographic phases and related quantities. Diffraction tomography is typically performed with monochromatic x-radiation and an area detector. This paper reports tomographic reconstruction with polychromatic radiation and an energy sensitive detector array. The energy-dispersive diffraction (EDD) geometry, the instrumentation and the reconstruction process are described and related to the expected resolution, and EDD tomography is contrasted with x-ray diffraction tomography with monochromatic radiation. Results of EDD tomography are presented for two samples containing hydroxyapatite (hAp). The first is a 3D-printed sample with an elliptical cross-section and contains synthetic hAp. The second is a human second metacarpal bone from the Roman-era cemetery at Ancaster, UK and contains bio-hAp which may have been altered by diagenesis. Reconstructions with different diffraction peaks are compared. Prospects for future EDD tomography are also discussed.

Computed tomography data in collections-based research: A 25 year survey

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Broad segments of the scientific community have for generations recognized that vouchered specimens, held in public trust institutions, are fundamental to scientific discovery and research. Vouchered specimens enable validation of discoveries, and their value only grows with reuse and repurposing. The last 25 years have seen exponential growth in the application of computed tomography (CT) to the analysis of vouchered specimens that range from meteorites to fossils to rocks and Recent biological samples. This growth was driven by the new basic discoveries that are being made from the datasets generated by CT and other non-destructive 3D imaging techniques. Insofar as many new discoveries derive from voxel data, those datasets take on an evidentiary standard comparable to the original specimens themselves. It follows that, ideally, the voxel datasets should themselves be vouchered for subsequent validation and re-use. However, this simple thought is complicated by intellectual property issues, by steady improvements in scanning technology, and by evolving computational environments. 3D imaging is often called a 'scientific revolution.' A brief survey of the last 25 years of scanning specimens from museum collections from around the world highlights aspects of the 'revolution' that remain nascent and unfulfilled. However, this history also points to expedient and effective measures that may propel 3D imaging into the revolutionary advancement that many of us envision.

MorphoSource: A virtual museum and digital repository for 3D specimen data

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Keywords: MorphoSource, 3D data, data stewardship, data access, digital repository, morphology, surface scan, microCT, laser scan

Over the past several decades, the use of 3D data has become increasingly common in biological and paleontological research, and techniques leveraging 3D data offer great promise for scientific advancement. Increasing availability of this data through sharing and archiving is a crucial step in breaking down barriers to progress, but achieving this goal poses challenges concerning implementation, stewardship, and incentivization. We describe MorphoSource, a web-based virtual museum and digital repository that has existed since 2013 and adheres to standards of data quality and format recently established by the community of scientists working with 3D data. At the time of writing, it holds over 21,000 3D datasets representing over 1,000 species. Users can upload and download high fidelity 3D renderings of specimens derived from a variety of scanning modalities. Specimens (ideally physically vouchered in a collection) comprise the basic unit of organization. Specimens are represented by media files and associated with metadata including project, scanning facility, institution code, and taxonomy, using best-practice standards where possible. Users who upload data maintain control over access to that data, and DOI identifiers can be generated that allow uploaders to be cited for usage of data when they share it. Shared

data can be easily searched and downloaded, and downloaded data can be used by researchers, educators, or other interested parties. MorphoSource represents a proof-of-concept for how to address challenges relating to increasing data access. Because of this, it is increasingly endorsed by major American specimen collections as an appropriate solution for hosting researcher-generated 3D data, and journal reviewers, editors, and grant officers have started to suggest or require that data be made available through this site. Its existence is beginning to change data transparency standards in comparative biology and paleontology.

Materials science applications of X-ray and neutron interferometry/tomography

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Keywords: interferometry, differential phase contrast, dark-field, Talbot-Lau

Grating-based interferometry is enabling new contrast mechanisms for X-ray and neutron tomography. Since 2016, we have used interferometers at the Advanced Photon Source 1-BM, NIST NG6, Helmholtz Zentrum Berlin CONRAD2, LSU CAMD synchrotron, and our own W.M. Keck laboratory system. The interferometer configurations have included Talbot, Talbot-Lau, and far field (Miao et al, Nature Physics, 2016, 12, 830). The data acquisition strategies have mostly been stepped-grating with some single-shot acquisitions. Our Mathematica interferometry codes have been converted to Python and deposited with the APS tomopy project. The materials science applications have ranged over additive manufacturing (polymers and metals), lithium ion batteries, twinned crystals, coastal sediments, and biological samples.

We built a laboratory X-ray grating interferometer with a novel gantry and rotisserie design. Interferometer stability was built into the instrument with consultation with a physicist from the LIGO project. The gantry permits observation of a stationary sample. The rotisserie enables multiple direction differential phase contrast imaging, where at least two orthogonal directions are required for phase integration. We built a synchrotron-based X-ray grating interferometer with precision grating rotation stages, again with the purpose of multiple direction differential phase contrast imaging. The upstream optics include a Laue monochromator currently operating at 38 keV.

The dark-field and differential phase contrast image modalities will be discussed in the context of 3D polymer printed test objects. The dark-field images reveal sub-pixel scattering features; feature size can be estimated from the interferometry setup.

Probing the microstructure of 3D-printed carbon fiber composites

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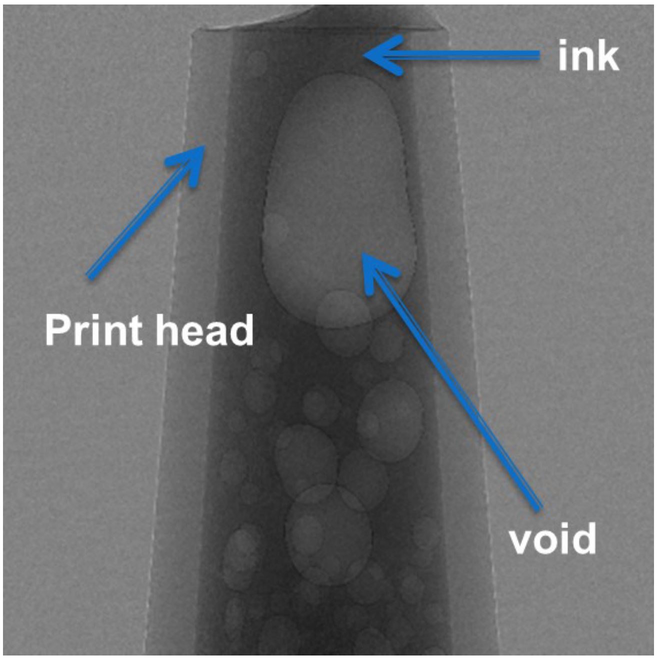
Keywords: X-ray CT; 3D-printing; carbon fiber composites

Additive manufacture (AM) of Polymeric composite materials to form parts, structures and devices with enhanced materials property sets and novel functionality is a rapidly growing area of materials science. As new manufacturing processes and materials feedstocks are rapidly developed and applied in this area, there is an increasing need to characterize and understand the physical microstructure of AM composite materials. Proper characterization of filler phase, voids, defects and engineered structure at a range of size scales and at different stages of an AM process is essential to the optimization and rational development of this potentially disruptive new technology. Here we present an overview of our efforts in the area of additive manufacture of carbon fiber/polymer composites and the use of micro and nano-X-ray computed tomography to assess the efficiency of developmental printing processes as well as the degree of ordering and alignment of fiber structures within printed parts (see Figure 1).



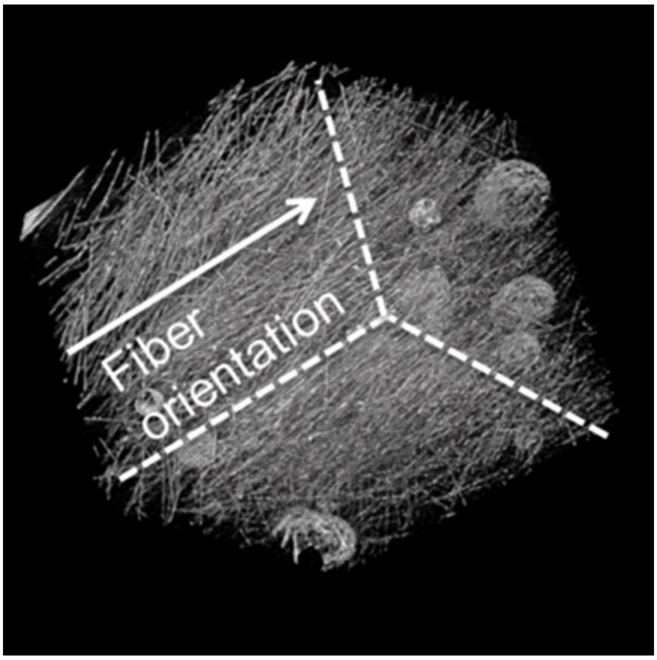


Figure 1. Left: An X-ray CT reconstruction of a failed experimental print-head for an AM carbon fiber printing process. Note that the nozzle exit diameter here is 250µm and we observe the presence of a series of voids which have formed in the resin extrudate, potentially indicative of cavitation on printing.

Right: High resolution X-ray CT image of a 3D-Printed Carbon fiber filled composite where the 7µm diameter fibers have been preferentially aligned on one axis. Both the degree of alignment and the presence of unwanted voids may be readily quantified from such diagnostic methods, allowing processes and materials to be rationally optimized without resorting to purely iterative design approaches.

The development of a combined experimental diagnostic and computational approach to understanding and optimizing fiber filled AM processes will be discussed as well as the unique advantages and challenges to the implementation of X-ray Computed Tomography for the characterization of Carbon fiber filled Polymer composites.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

X-ray computed tomography to quantify above- and below ground structures for an integrated understanding of plant form and function

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Donald Danforth Plant Science Center, St. Louis, MO

Keywords: X-ray CT, plant biology, root system architecture

Non-destructive sampling and analysis in plant biology have long been sought after to enable substantive research into the quantitative genetics of agronomic traits. X-ray computed tomography (CT) has been used widely since the 1970s in medical and industrial applications, but its use in plant biology has been sporadic at best. The Topp lab at the Donald Danforth Plant Science Center obtained an industrial scale X-ray CT instrument in August 2016 and we have been exploring a wide range of applications for non-destructive imaging in plant biology since that time. We have generated hundreds of 3D volumes from scanning above-ground structures such as sorghum seed heads and grape rachis structures that determine fruit yield and quality, embryos within overwintering grape buds and maize seeds, as well as excavated root crowns, and a variety of plant seedlings. These 3D volumes were used directly to assess a range of traits that contribute to agronomic quality using feature extraction algorithms. We have also been using X-ray CT to scan plant roots, followed by image segmentation of the resulting 3D volume to separate root systems from the growth medium, in order to analyze potentially advantageous root traits. Further advancement of our imaging and segmentation technology will provide a wealth of new information and understanding of crop genetics, and the location of an X-ray CT system at the Danforth Center, dedicated exclusively to plant biology, is poised to transform X-ray imaging from a nascent technology to a cornerstone of plant science research.

Using iodine-contrasted μCT to facilitate imaging of structural brain defects

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Here we report the loss of Kinesin family member 6 (KIF6) function results in structural malformations of the brain. In humans, we report a single pedigree with a proband that displays a homozygous non-sense allele of KIF6. Clinical features include macrocephaly, intellectual disability, low-set prominent anti-helical pinnae, and slight scoliosis. This *kif6* mutant is homozygous viable despite displaying recessive, severe late-onset curvature of the spine or scoliosis. Interestingly, the loss of cerebral spinal-fluid flow (CSF) during early larval zebrafish development was shown to elicit late-onset scoliosis, as well many neurological abnormalities in humans that are known to display a secondary scoliosis. We find that *kif6* mutant zebrafish display a reduction of ependymal cell cilia (ECC), which are structures important for normal CSF in the brain. Using iodine-contrasted μCT analysis of these mutant zebrafish we show multiple dilated ventricles and severe changes in normal brain structures. Moreover, we also find that *Kif6* mutant mice display severe structural defects of the brain including dilated ventricles and dysmorphogenesis of normal brain structures. We are underway with comprehensive iodine-contrasted μCT analyses of the brain in our existing collection of zebrafish scoliosis mutants. Our work seeks to understand the genes and pathways that contribute to normal brain hydrodynamics and has implications for understanding conserved mechanisms of spine stability in humans.

Exploring the relationships between locomotor behavior and semicircular canal morphology in squamates: Preliminary results

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Keywords: vestibular organ, semicircular canals, locomotion, ecomorphology

We employ measurements of digital endocasts of the semicircular canals (SCC) of 55 extant squamate taxa, to explore the relationship between ecological niche, locomotor behaviors, and the geometry of the semicircular canals. Contrast of log radii of SCC with log body mass reveals scaling similar to the results of Spoor et al. (2002) and a linear regression of these data nearly overlie that of the non-cetacean mammals in that study. Five small (3 meter) to medium sized (5.5 meter) mosasaur taxa of a single subfamily, ranging from Lower Turonian to Maastrichtian in age (~94Ma-66Ma) were added, plotting well above the extant squamate trend-line due to relatively larger SCC but exhibiting similar scaling. A Pearson type principal component analyses indicate arboreal and scansorial taxa tend to have larger SCC relative to the mean variance of the dataset. Extant aquatic taxa in our sample have relatively smaller SCC but a larger lumen of the horizontal SCC. Fossorial forms tend to have smaller SCC's as do legless forms (snakes and lizards). Repeated measures ANOVA with mixed models found that the SCC radii and lumen radii were consistent, validating use of their averages for future tests. Preliminary results indicate SCC radii alone are insufficient to segregate ecomorphological groupings, but addition of other metrics such as lumina diameter allows discrimination.

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Impact and potential of computed-tomography in paleontology & archeology

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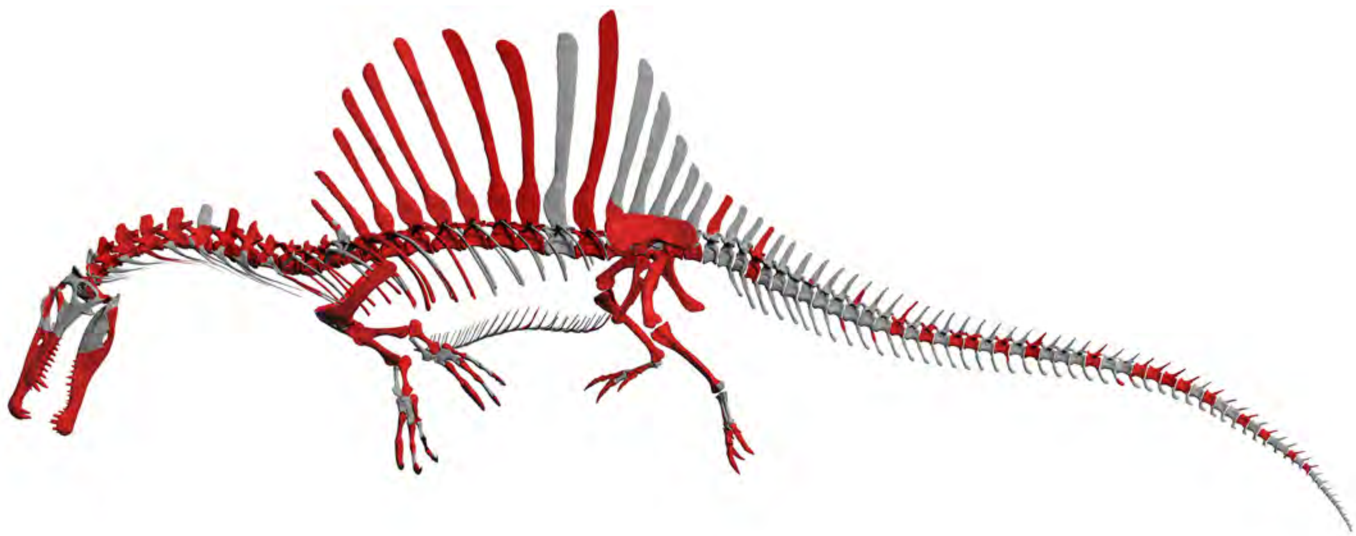
Keywords: paleontology, archeology, 3d modeling, rapid prototyping, reconstruction, visualization, fossil

Computed tomography, now widely used in paleontology and archaeology for nondestructive internal visualization, has opened the door to a wide range of static and dynamic visualizations and rapid-prototyped models. At universities and collaborating medical and industrial institutions, paleontological and archeological specimens are routinely scanned for scientific research and publication, popular static and dynamic visualization in film, database archiving, and rapid prototyping. Whereas a high-energy microCT scanner is preferable for small objects, a high-resolution medical CT scanner allows the scanning of much larger objects. Many paleontological and archaeological specimens are too large for a microCT scanner. Scanning hundreds of fossilized specimens has led to the optimization of scanning parameters for imaging paleontological specimens on high-resolution medical CT scanners. Although initially used for surfacing and segmenting internal spaces such as endocasts, tomographic scans have now been used to resize, articulate, measure, figure, and prototype bones for reconstructing large dinosaurs and section and reconstruct partial ceramic vases. Tomographic data also have been used to reconstruct skulls, unwrap and calculate the stature of fossil human skeletons, test proposed gaits and other actions of extinct species, and create fly-throughs of large skulls and skeletons.



Using Micro-CT to unravel past bleaching events of Chagossian corals

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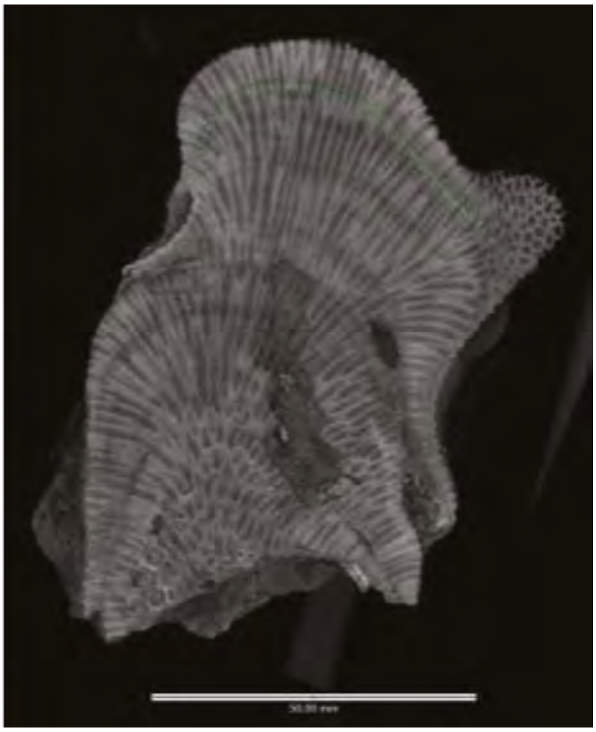
Coral bleaching resulting from elevated sea surface temperature is expected to increase in frequency and severity throughout the 21st century. We need to document past responses in order to understand how recovery times are changing due to increased frequency of events. This is challenging because most reefs have long been subject to anthropogenic impacts. The Chagos archipelago, central Indian Ocean, is one of the most pristine environments in the world (Figure 1), so is an ideal system to study recovery responses. More than 6000 whole coral colonies were collected from the Chagos during the 1970s, a period of time that included a strong thermal event. These collections are currently held in the Natural History Museum and form the basis for this study. During preliminary investigations, micro-CT scans of 14 colonies revealed a common stress band that correlated with this event (Figure 2). We have compared growth and bioerosion rates before and after this event across a number of species, to see how corals are responding to bleaching. Here we present the findings of this study within the context of opportunistic bioeroders and reduced growth.



(Left) Figure 1. Map of the Indian Ocean, with an insert showing the geography of the Chagos archipelago.

(Right) Figure 2. Rendering of a Chagossian Porites sp. specimen that was collected during the 1975 Joint Services Expedition to Egmount Island. The 1972 stress band is above the dotted line.

High resolution 3D imaging in biology and surgery: the role of micro ct in the clinical and research lab

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Micro CT has an enormous potential for providing high resolution 3D imaging in biology and surgery. On the biological side, my own group has been interested in using Micro CT to apply geometrical principals to the understanding of the 3D packing of anatomical structures such as the liver lobule or lung acinus. A more general project of my group has concerned the creation of a new, multi-institutional project for sharing and viewing high resolution 3D data of objects of interest, the "Virtual Museum of Natural History"™ (VMNH). The VMNH project has already collected 1200 Micro CT stacks of ~900 specimens, including 722 mollusk shells of 198 species in 172 genera, animal eyes, marine eyes, de-identified human autopsy specimens, brittle worms, annelids, cephalopods, various vertebrates, and seaweeds. The VMNH project will be run on the principle that users who prepare a publication using VMNH datasets agree to offer co-authorship to the original up-loaders of the stacks, so as to motivate participation on both providing and using data. Videos of many VMNH specimens can be seen on our YouTube Channel: youtube.com/channel/UCGCBXNkhm6BMQxtV_Thvkmw. On the medical side, the absence of rapid, detailed, 3D, information on surgical specimens has long been a major barrier to success in many aspects of surgery, especially in cancer surgery. For example, at the present time, approximately 1 in-3 breast cancer patients go home with cancer in them, a fact that is not discovered until a week later, when the pathology slides are examined, requiring return to the hospital for a re-excision operation. In a small number of patients, cancer remains at the surgical site, which is not known until many months or even years later when a local recurrence occurs, increasing the individual's chance of death by 22%. This results in approximately 2,000 deaths each year in the USA alone, deaths which might be prevented by detection of the residual cancer at the time of the initial surgery. We have demonstrated that Micro CT can provide useful 3D images for many surgical specimens, including identifying margin positive breast cancer patients in 10 minutes, and locating lymph nodes. This work has shown that Micro CT can provide rapid, accurate, actionable information on the surgical specimen while the patient is still in the OR.

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Poster Abstracts

Using computed tomography to digitally prepare vertebrate fossils from field jackets

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Keywords: Vertebrate paleontology, fossils, computed tomography

X-ray computed tomography (CT) is increasingly used by paleontologists as a tool to visualize anatomical features of fossil specimens physically obscured by rock matrix. CT is often utilized to augment or replace manual preparation of vertebrate fossils from plaster field jackets in cases where a specimen is delicate or where the contents of a field jacket are undocumented or otherwise unclear. This approach yields volumetric models of individual bones generated by removing matrix from the surface of the fossil bone digitally. I present here a case study of vertebrate specimens that were digitally prepared from CT scans of field jackets in this manner. This study comprises several specimens of the early armored dinosaur Scutellosaurus lawleri collected from the 'silty facies' of the Lower Jurassic Kayenta Formation in northeastern Arizona. The specimens of Scutellosaurus lawleri are disarticulated, fractured, and compressed taphonomically with many elements closely appressed to one another, making their removal from the surrounding rock matrix in their field jackets difficult. Specimens were mechanically prepared until risk of damaging the fossil bone was deemed too high, at which point the specimens were CT scanned at The University of Texas High Resolution X-ray Computed Tomography Facility. These CT scans were used both to guide further mechanical preparation and to digitally reconstruct a partial cranium from disarticulated elements preserved in one specimen, which subsequently yielded novel information about the cranial morphology of Scutellosaurus lawleri.

Detecting flaws in additive manufacturing and lithium polymer batteries through X-Ray and neutron interferometry and tomography

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Keywords: X-ray and neutron tomography, grating interferometry, additive manufacturing, lithium polymer batteries

X-ray and neutron tomography offer unique access to detecting flaws in additively manufactured (AM) samples and lithium polymer (Li-po) batteries [1]. Access to sub-pixel defects is enhanced by interferometry methods [2,3] and leads to a range of applications for materials science [4,5]. Herein, we explore the correlation [6] between two interferometry imaging modalities, absorption and dark-field (scattering), as an efficient strategy for defect detection and characterization. The underpinning for interpreting the dark-field images comes from the X-ray and neutron scattering community [7]. Recently, we have been comparing two interferometry designs, both based on grating interferometry. Grating interferometry typically uses micron-dimension linear structures fabricated on Si-wafers; the linear structures can be used as either absorption or phase shift material. A Talbot-Lau interferometer is constructed with one phase shift and two absorption gratings and this design accounts for most of the recent interferometry publications. A second design, a far-field interferometer [8], can be implemented with one absorption and two phase shift gratings. X-ray interferometry was performed at the LSU synchrotron CAMD. Talbot-Lau neutron interferometry was utilized at the Helmholtz-Zentrum Berlin CONRAD-2 beamline and far-field neutron interferometry at the NIST NG6 beamline. The dark-field image contains orientation information

[4,5] and we are finding that AM flaw detection often requires two orthogonal setups of the interferometer or sample. The dark-field signal was monitored as a function of autocorrelation scattering length for fresh and worn Li-po batteries at various charge states. The particle size was found to change with battery fatigue.

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Characterizing variation in proximal humerus trabecular bone structure in modern humans using microCT and whole joint methodologies

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Keywords: microCT, Medtool, human skeletal variation, trabecular bone

Recent studies have demonstrated that trabecular bone robusticity in the proximal femur of foragers is similar to non-human primates, but that agricultural populations fall well below the non-human primate distribution. However, the influence of repetitive loading and behavioral differences on trabecular bone structure in humans remains unclear. This project investigates trabecular bone structural variation in the proximal humerus of five modern human populations with varying subsistence patterns. As the upper limb analog to the proximal femur, the proximal humerus is of interest because it is not continuously loaded during locomotion, but experiences forces from multiple directions during various daily activities. Proximal humeri of 74 adult humans from five distinct populations and 32 individuals from three non-human primate species were microCT scanned. Trabecular bone structure was analyzed using BoneJ. All human populations fall below the primate distribution for bone volume fraction (BV/TV). Within humans, forager and early agricultural populations have significantly higher BV/TV and thicker trabeculae than complex society agriculturalists and post-industrial revolution populations. Further, five individuals from each population with the highest, lowest, and median BV/TV were analyzed using whole joint methodologies in MedTool. Whole joint analyses were used to qualitatively asses the patterns of BV/TV and Young's modulus between species and populations. Overall, results indicate reduced skeletal robusticity in the human proximal humerus, but do not exactly mirror patterns found in the proximal femur. Utilizing microCT and whole joint analysis methods greatly enhances our understanding of variation in modern human skeletal phenotypes associated with diverse subsistence strategies.

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Variation in the trabecular structure of the proximal tibia between obese and non-obese individuals

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Obesity adds a biomechanical burden to the human knee joint. Since mechanical usage influences trabecular architecture, differences between obese and normal weight individuals should be reflected in the trabecular structure of the knee joint. In this study, we conduct an assessment of the differences in trabecular architecture of the proximal tibia in obese and non-obese individuals, as determined by body mass index (BMI) at death. High-resolution computed tomography was used to scan the left tibia of ten obese and ten non-obese, age-matched females, and ten obese and ten non-obese, age-matched males. A cubic volume of interest (VOI) was extracted from below the center of the medial and lateral condyles of each tibia. Bone volume fraction, connectivity density, degree of anisotropy, and trabecular thickness and separation were calculated for each VOI. Two-tailed t-tests show that obese individuals have lower trabecular separation in the medial condyle. Connectivity density, a proxy for trabecular number, is significantly greater in obese individuals, also only on the medial side. There is a nearly significant difference in anisotropy in the medial condyle, with obese individuals having less directionally oriented trabecular structures than non-obese individuals. Bone volume fraction and trabecular thickness are not significantly different for either condyle. The results of this study suggest that the biomechanical burden of obesity is reflected in the proximal tibia trabecular structure. The differences between obese and non-obese individuals are more pronounced in the medial condyle and are due to the addition of trabeculae in obese individuals rather than an increase in the trabecular thickness. This study contributes to our understanding of how obesity affects the skeleton, and more broadly how bone reacts to mechanical usage.

This research is supported in part through instrumentation funded by the National Science Foundation under Grant NSF:MRI 133804.

The effect of mobility impairment on femoral trabecular and cortical bone structure

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Reduced mobility or long-term immobility results in diminished muscular stress and normal weight bearing on the lower limb bones. Since mechanical usage influences trabecular architecture and cortical density, reduced ambulatory ability should be reflected in the trabecular structure and cortical area of the proximal femur. In this study, the proximal femur of mobility-impaired and normal mobility individuals was assessed for differences in trabecular architecture and cortical area. High-resolution computed tomography was used to scan the femora of twenty-eight mobility-impaired and twenty-eight age, sex, and BMI (when possible) matched normal mobility individuals. A cubic volume of interest (VOI) was extracted from the center of each femoral head. Bone volume fraction, connectivity density, degree of anisotropy, and trabecular thickness and separation were calculated for each VOI. Kruskal-Wallis tests show that mobility-impaired individuals have significantly less bone volume fraction and trabecular thickness and greater trabecular spacing than normal mobility individuals. Connectivity density and degree of anisotropy show no significant difference between mobility impaired and normal mobility individuals. This indicates that mobility impairment is causing bone to be lost from each trabecular strut, losing thickness, rather than by entire trabeculae being resorbed. Additionally, cross-sectional slices of the cortical bone at the midpoint of the femoral neck, subtrochanteric, and midshaft of the femur show that mobility-impaired individuals have less cortical area in all directions than do normal mobility individuals. The results of this study suggest that the lack of biomechanical burden on mobility-impaired individual femora is reflected in their trabecular structure and cortical bone. This has implications for identifying mobility impairment in the forensic and archaeological context, as well as for comparison with studies using bone microstructure to analyze mobility and subsistence patterns over time.

This research is supported in part through instrumentation funded by the National Science Foundation under Grant NSF:MRI 133804.

Establishing the variation of dermal sculpturing within Gekkota

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Traditionally geckos are described as having a smooth skull that lacks dermal sculpturing. We observed 22 bones from the skull in 107 gecko genera using a diversity of methodologies, including high resolution X-Rays and computed tomography scans. The results from the observations were optimized in an existing tree topology based on a multigene tree. Our main finding from the evaluation of dermal skull bones indicates that there is no such general pattern of smooth dermal bones in geckos. In fact geckos display a huge diversity of sculpturing patterns in the skull bones.

Learning to swim: evolutionary transition from terrestrial to aquatic life in South American coralsnakes

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Keywords: CT, X-ray, morphology, snake, evolution, biology, ecology

Without limbs for grasping or climbing, snakes must use only bones and associated musculature of their skull and spine to successfully thrive in their environment. Among snakes, those in aquatic environments differ in substantive ways from terrestrial snakes: more teeth, flatter skulls, flattened tails, etc. We investigated the transition from terrestrial to aquatic life in a radiation of new world elapid snakes, coralsnakes in the genus Micrurus. Using a phylogenetically-aware analysis of morphology, we used high resolution computed tomography (CT) to study skull and vertebral morphology. We document character evolution in this ecological transition and analyzed these data using three-dimensional geometric morphometrics. By comparing our taxa to more distantly related coralsnakes, we reconstruct the evolution of Micrurus morphology and, by extension—ecology, over transitions to aquatic life. We briefly discuss taxonomic recommendations within the M. lemniscatus complex. We also discuss our ongoing study seeking parallel adaptations to aquatic life in the Asian elapid snakes. CT scanning allowed us to non-invasively study exceedingly rare museum material. We conclude by discussing emerging collaboration between the UT Arlington Reptile and Amphibian Diversity Research Center and the Shimadzu Institute for Research and Technology.

Accretion of fine-grained rims in a turbulent nebula for CM Murchison

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We use X-ray computed tomography (XCT) to examine the 3D morphology and spatial relationship of fine-grained rims (FGRs) of Type I chondrules in CM Murchison to investigate the formation setting (nebular vs. parent body) of the FGRs. We quantify the sizes, shapes, and orientations of the chondrules and their rims and develop a new algorithm to examine the 3D variation of FGR thickness around each chondrule. We find that the average proportion of chondrule volume contained in the rim for Murchison chondrules is 35.9%. The FGR volume in relation to the interior chondrule radius is very well described by a power law function as proposed for accretion of FGRs in a weakly turbulent nebula by Cuzzi (2004). The power law exponent indicates that the rimmed chondrules were slightly larger than Kolmogorov-stopping-time nebular particles. FGR composition as inferred from CT number appears essentially uniform across interior chondrule types and compositions, making formation by chondrule alteration unlikely. We determine that the chondrules were deformed and foliated by the same impact event(s) that deformed CM Murchison (Hanna et al., 2015) and that the FGRs were compressed in the direction of maximum stress, resulting in rims that are consistently, slightly thicker in the plane of foliation. Finally, we propose that the irregular shape of some chondrules in CM Murchison are a primary feature resulting from chondrule formation and that chondrules with a high degree of surface roughness accreted a relatively larger amount of nebular dust compared to smoother chondrules.

X-ray interferometry/tomography of 3D printed flame retardants/ABS structures

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Keywords: interferometry, European Union glow-wire flame retardant test, fused deposition modeling

Flame retardant/polymer testing is done with test bars subjected to heat or flame in tests such as the European Union glow-wire test [1] and the Underwriters Laboratory 94 methane flame test [2]. A conventional extruded polymer test bar is a homogenous blend of flame retardant and high impact polystyrene; the 12 wt% flame retardant sample passes the UL 94 test while the 3 wt% sample fails. The 3D printed test bars used in this work have several layering structures created with a dual filament printer using the fused deposition modeling technique. One filament is acrylonitrile butadiene styrene polymer (ABS) and the second filament is flame retardant/ABS. 3D printed test bars were printed in several structures: (a) 100% flame retardant/ABS filament, (b) a 1:1 layered structure of flame retardant/ABS and ABS filaments, and (c) a 1:3 layered structure of flame retardant/ABS and ABS filaments. One goal is structures which efficiently use flame retardants in near-surface layers, with a pure polymer surface layer for wear and durability.

The glow-wire test was adapted for the CAMD tomography/interferometry beamline. Stepped grating X-ray interferometry [3,4] was performed as a function of brief heating episodes to observe the evolution of the absorption, dark-field (scattering) and differential phase contrast images. The heater was positioned on a counterweight-trolley-rail system ensuring constant 1 Newton force on the deformable sample. This setup allowed automated, repetitive near-burning and interferometry 2D imaging. Post-heating, samples were selected for interferometry/tomography.

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The antiquity of the unique basicranial circulation pattern in the Mosasaur Subfamily Plioplatecarpinae

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Keywords: Phylogeny, Tropic Shale, Cretaceous, Plioplatecarpinae

A new mosasaur taxon from the Lower Turonian part of the Tropic Shale in Utah preserves significant portions of the skull and axial postcranial skeleton, displaying a remarkable mosaic of primitive and advanced features, elucidating polarity of certain characters, and allowing reassessment of the basal relationships of major mosasaur clades. Certain key characters were assessed using high resolution CT scans, specifically, reconstructions of basicranial vascular patterns for a large number of mosasaur taxa, ranging from Lower Turonian to Upper Maastrichtian in age (~94 Ma-66Ma). The basisphenoid in the new taxon displays a novel pattern similar to other non-tylosaurine Russellosaurian mosasaurs in which the anterior opening of the vidian canal is bifurcated, the dorsal branch paralleling the palatine branch of the carotid artery anteriorly and posteriorly trending medially to enter the basisphenoid anterorolateral to the dorsum sellae, terminating in a vestibule. In the new taxon and other basal forms, the vestibule communicates with a large median foramen just ventral to the dorsum sellae. In more derived plioplatecarpines the posteromedian branches follow the same anterior path as stated above, but does not emerge at the dorsum sellae, but instead continues posteriorly, crossing the basisphenoid-basioccipital suture and exits into the medullary cavity on the dorsal surface of the basioccipital. This morphological complex is unique amongst squamates and supports inclusion of the new basal taxon, along with two previously described basal forms, Tethysaurus and Russellosaurus, in a monophyletic clade with more derived plioplatecarpine mosasaurs.

Soundscape detection by fishes through the interaction of the swim bladder and otoliths

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Keywords: fish, larvae, swim bladder, sound, resonance frequency, acoustic cues, modelling, ecology, microCT

Fishes live in a sensory world dominated by sound due to the physics of the underwater environment. However, uncertainty about the sensitivity of fishes to sound pressure challenges our understanding of the role of acoustic cues in their life history. This is of particular interest for fish larvae, as in many species a habitat shift is required at the end of the larval stage and acoustic cues are hypothesized to help larvae locate and select suitable habitat. To do so fishes must use the pressure component of sound, enabled by the interaction between the swim bladder and otoliths. Given the complexities inherent to studying fish larvae on the order of millimeters, we explored this mechanism of pressure detection using finite-element modelling of swim bladder and otolith surfaces acquired from high resolution X-ray microCT data. Our first goal was to determine the resonance frequency of the swim bladders, because it is at this frequency where the most movement, and possibly sensitivity, will occur. Our second goal was to determine how movement of the swim bladder causes movement of the otoliths across a range of frequencies. As a proof of concept we first modeled the resonance frequency of swim bladder surfaces from adult zebrafish (Danio rerio) and compared results to geometric shapes for which we could verify model results using analytical solutions. Next, we modeled the swim bladder resonances and otolith motion using larvae of red drum (Sciaenops ocellatus) in order to address questions of acoustic cue use in early life stages.

Consequences of miniaturization in the cranial osteology of lizards and snakes

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Miniaturization, the development of extreme body size, has evolved in at least 24 families within Squamata. In miniaturized skulls (~ 15 mm skull length or less), the space between the otic capsules is minimal. Given the large number of miniaturized groups, a general review of this evolutionary process and its consequences in the squamate skull is warranted. In this review, we assemble morphological changes previously attributed to miniaturization, together with new observations. General cranial features of miniaturized squamates include: 1) The relative increase in size of the neurocranium and its positioning at the same level as the dermatocranium; 2) the occipital condyle located at the posterior-most position of the skull; 3) the closure or reduction of the post-temporal fenestra; 4) the proportional expansion of the otic capsules; 5) elongation of the skull, with a 1:1 proportion between the snout and parietal units; 6) widening of the snout; and 7) short and stout paroccipital processes. Although a combination of these features is common among small squamates, at extreme miniaturization some groups exhibit morphological disparities. For example, small chameleons (Brookesia minima) have a short and anteroposteriorly compressed snout, resulting in a shortened skull, while small geckos have long (Sphaerodactylus ariasae) or shortened (Chatogekko amazonicus) snouts. Furthermore, while the majority of miniaturized squamates undergo closure of the post-temporal fenestra, in dwarf chameleons this opening remains open and proportionally large. Although miniaturization might also produce many convergent features among squamates (e.g., fossorial reptiles), in some groups (e.g., Chameleons) it results in distinctive morphologies.

Correlating Cu-Fe sulfides and Au mineralization in the Ertsberg-Grasberg District of Papua, Indonesia using high-resolution X-ray computed tomography: Modified Voronoi regions in Cu-sulfide pathways

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Keywords: HRXCT, sulfide, gold, ore, Indonesia, Voronoi

The Ertsberg-Grasberg District in Papua, Indonesia hosts two of the largest intrusion-related Cu-Au deposits in the world: the Ertsberg Intrusive System and the Grasberg Igneous Complex. Cu mineralization within the Grasberg porphyry and Ertsberg skarn systems consists primarily of bornite and chalcopyrite, where Au grains occur as inclusions within, or along boundaries of, these minerals. This study aims to constrain the potential connection between Cu-sulfides and Au-grains. At hydrothermal ore-forming temperatures (~300° - 700° C) bornite and chalcopyrite can host up to 1800 ppm Au within the sulfide lattice or as nano-inclusions. Upon retrograde cooling of the hydrothermal system, the ability of the Cu-sulfides to host Au decreases significantly to ~10 ppm, suggesting that the Au has passively migrated out of the Cu-sulfides and coalesced to form Au grains. The traditional model for gold deposition in large-scale porphyry and skarn systems relies primarily on fluid pulses and does not consider gold contributions from gold within Cu-sulfides. We use HRXCT to model 3D Voronoi regions within the Cu-sulfides, which represent diffusional regions that may have provided gold to the Au grains during cooling. The Voronoi regions are defined by the set of points restricted to the Cu-sulfide network of a sample that, when measured along a path through the Cu-sulfide, are closer to a specific Au-grain than to any other Au-grain. Eleven ore samples were scanned at UTCT, and of the resulting correlation coefficients for Cu-sulfide Voronoi region and Au-grain volumes only three show statistically significant correlation coefficients ($r > 0.5$).

Workflow for tomography inspection of additive manufacturing samples

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Keywords: Additive Manufacturing, VisTrails, TomoPy workflow

An efficient workflow is needed for the rapid processing of complex interferometry/tomography data sets of additive manufacturing (AM) samples. Recently, our Mathematica codes for interferometry have been uploaded to the tomopy project sponsored by the Argonne National Labs, Advanced Photon Source.

X-ray interferometry/tomography of 3D polymer printed samples, both ABS and PLA polymers, show filament-to-filament cracks and voids. The print defects are partially correlated with printhead trajectory. The improvement of print technology will require efficient workflows to close the loop of printer development with quality control analysis.

The tomopy workflow uses a Jupyter front end to access the tomopy Python codes. The interferometry data consist of interferograms at each tomography rotation angle. The data processing workflow has a number of variables: grating step vector, selection of a normalization region, selecting the appropriate reference interferogram for each sample interferogram, centering, and number of iterations in the SIRT reconstruction. The sample and X-ray interferometry both have orientation dependencies, leading to a large set of related experiments.

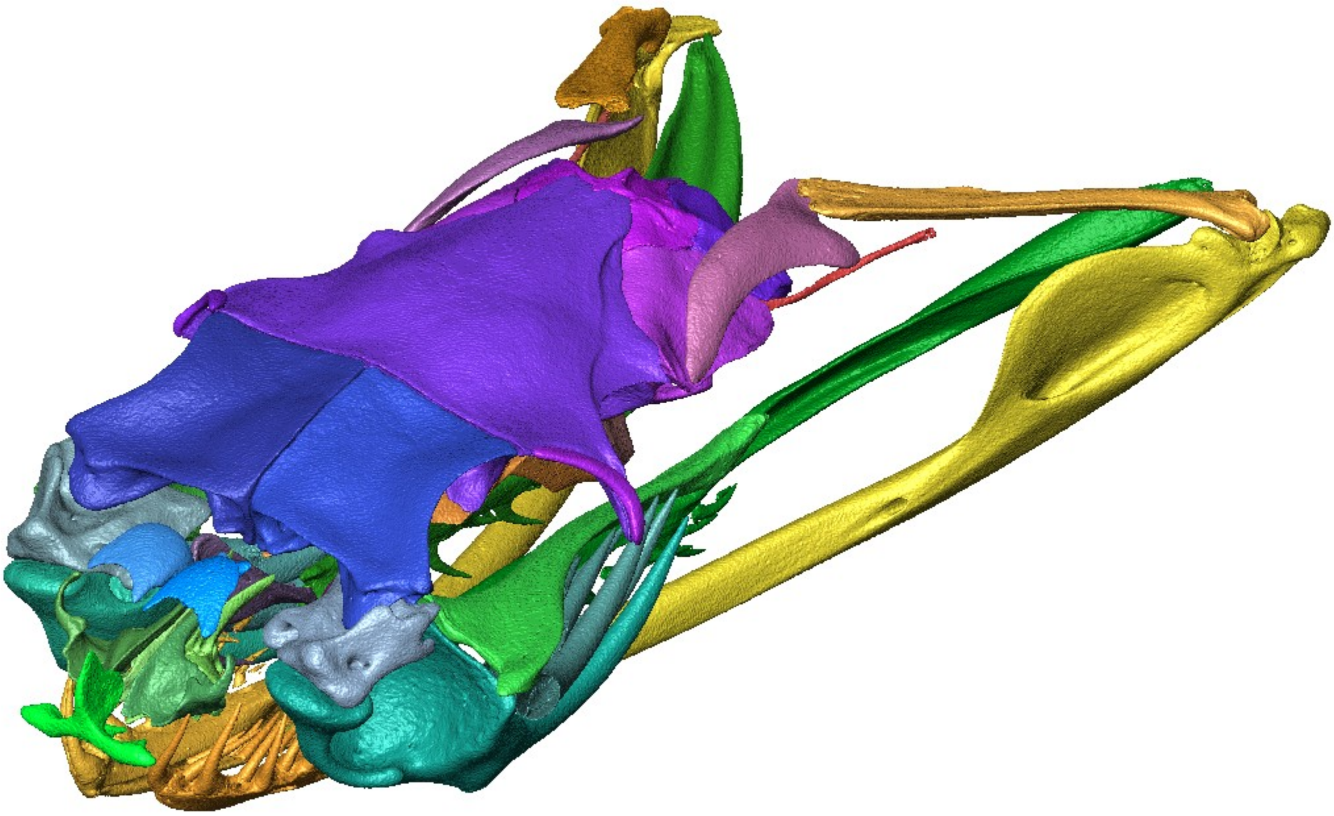
RMS | ToScA Membership

The Royal Microscopical Society and the ToScA group of the Natural History Museum now offer joint membership. Many attendees to this ToScA North America 2017 Symposium have already signed up.

ToScA, Tomography for Scientific Advancement, is a rapidly expanding group focussing on the practice of tomography and its many applications in both life and physical sciences. Their annual symposiums, hosted by the RMS in the UK and now the United States, always boast a top line-up of speakers and engaging submitted talks as well as extra opportunities such as training workshops.

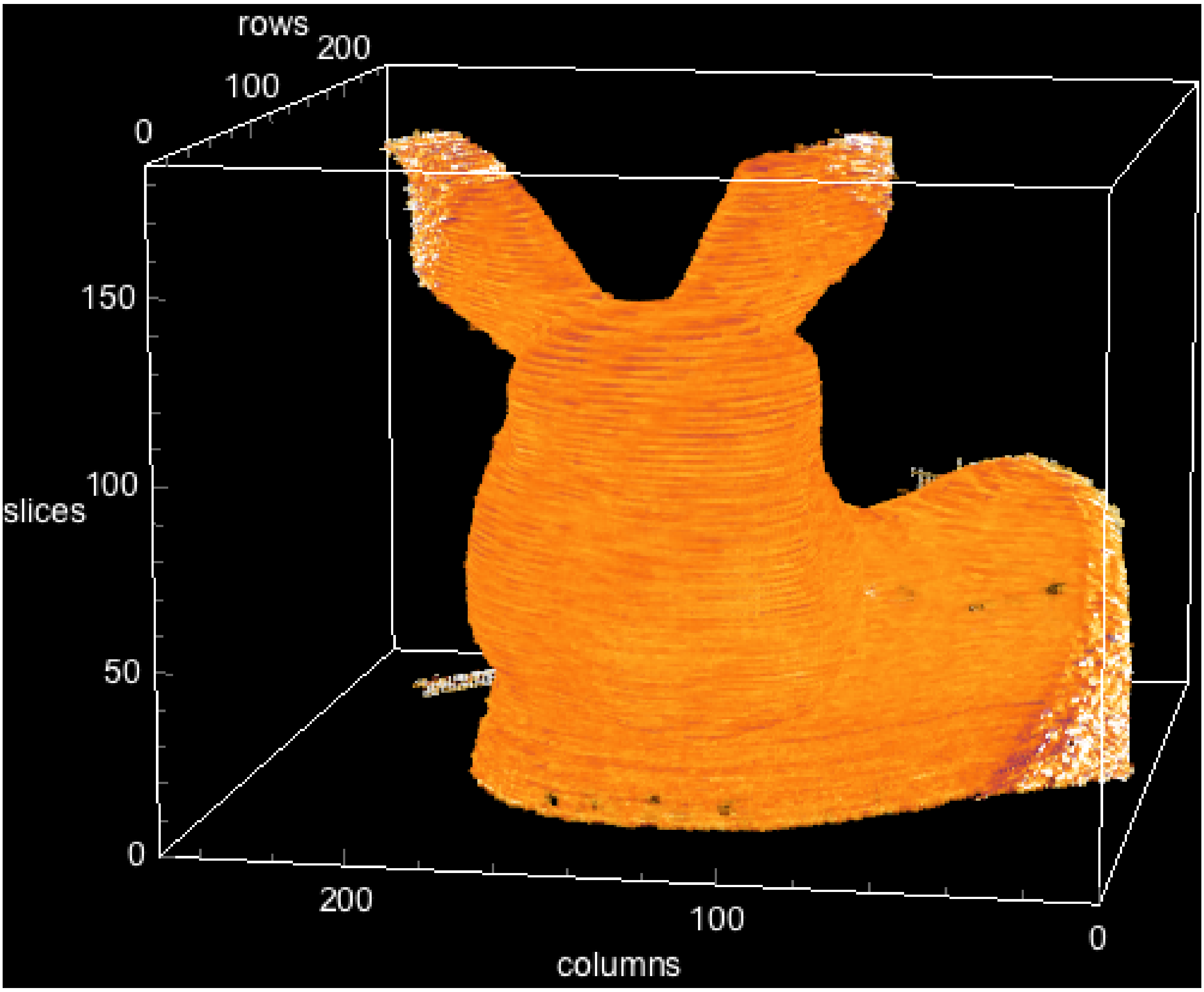
RMS | ToScA members will enjoy all the benefits of individual RMS membership, including discounted subscription to the Journal of Microscopy, RMS travel bursaries and free subscription to infocus magazine, as well as enjoying new, exclusive ToScA benefits. These new benefits, which are open to both student and standard members, are discounted registration to the ToScA meetings, access to ToScA bursaries and free attendance to ToScA workshops.

Information on signing up can be found at www.rms.org.uk/tosca



Imaging Competition

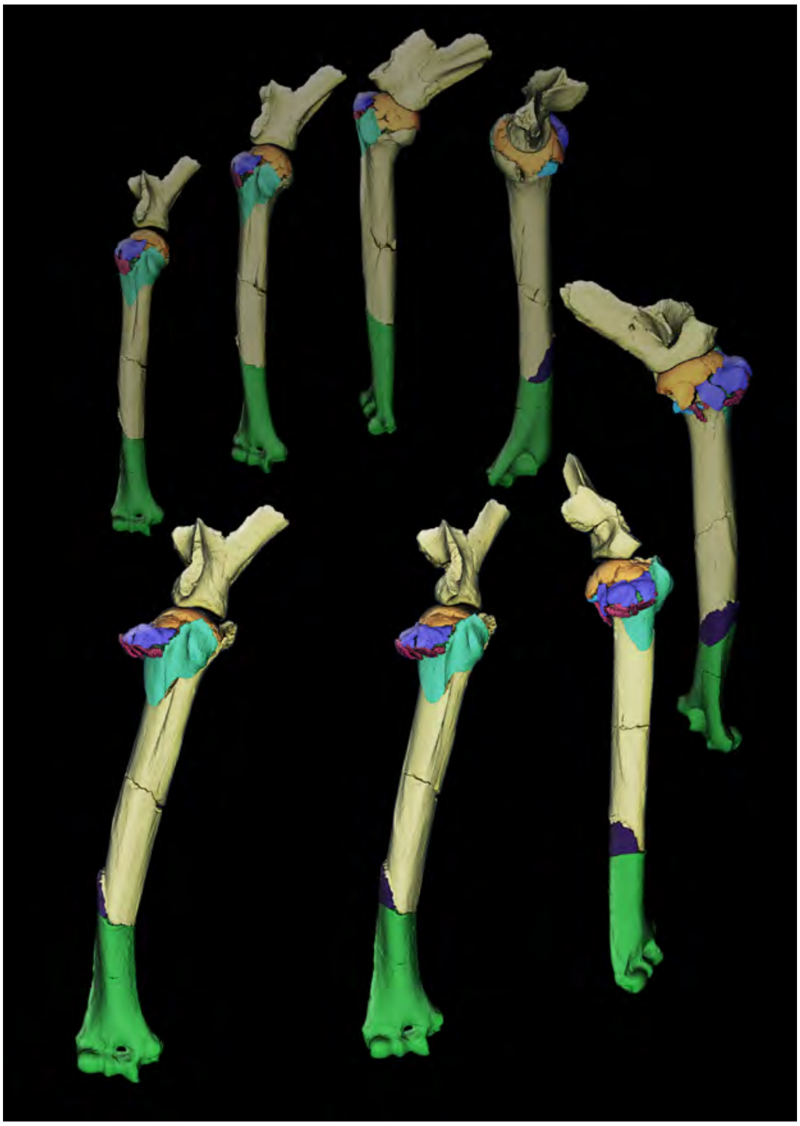
Thank you to those who entered the ToScA Imaging Competition. Although we did not receive enough entries to put together a judging panel, we wanted to showcase the submissions here.



Reconstruction of dark-field and vertical bunny

3D volume of dark-field bunny

Miss Jumao Yuan, Louisiana State University



The etiology of the fracture of Lucy's right proximal humerus

3D reconstruction of the right humerus and scapula of "Lucy," a 3.18 million-year-old female australopithecine from Hadar, Ethiopia, as based on high resolution CT scans. The humerus preserves evidence of a four-part proximal humerus fracture along with a spiral fracture in the shaft produced when Lucy suffered a severe impact from a fall, presumably out of a tall tree. The reenactment of the injury begins at top left with a reconstruction of the elements before the injury, with the articulated humerus and scapula spinning clockwise on their vertical axis while the compressive fracture progresses in a clockwise direction around the circle. The discovery state is shown at bottom left. Different colors represent fractured bone fragments. The impact also produced severe concomitant fractures across many other joints in the skeleton. These fractures along with the presumed damage to her internal organs are hypothesized as the cause of Lucy's death.

Dr John Kappelman, The University of Texas, Austin, TX

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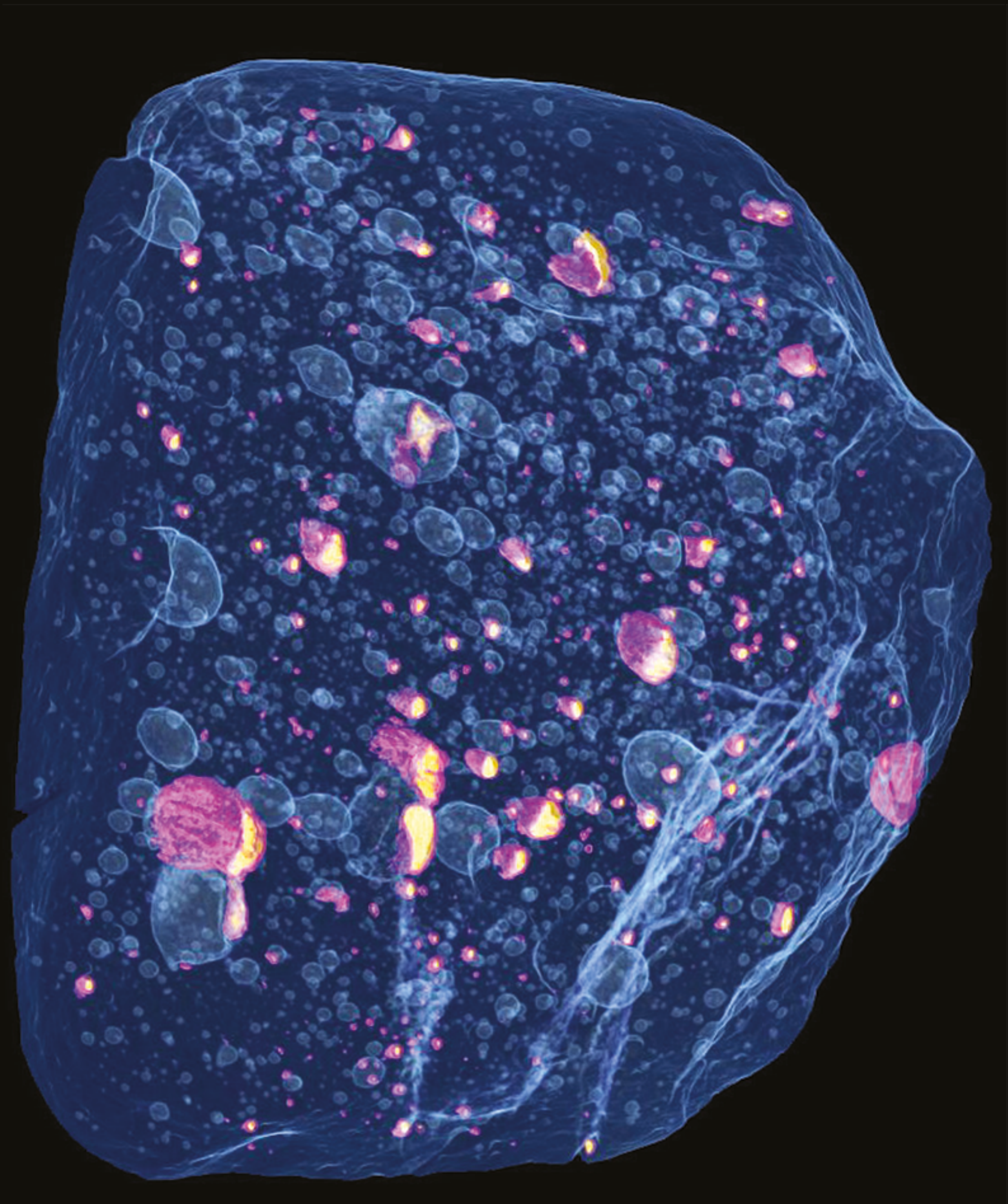

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